CHALLENGES OF SUSTAINABLE URBAN PLANNING: THE CASE OF MUNICIPAL SOLID WASTE MANAGEMENT

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Ning Ai

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CHALLENGES OF SUSTAINABLE URBAN PLANNING:
THE CASE OF MUNICIPAL SOLID WASTE MANAGEMENT

Approved by:

Dr. Nancey Green Leigh, Advisor
School of City and Regional Planning
Georgia Institute of Technology

Dr. Steven P. French, Co-Advisor
School of City and Regional Planning
Georgia Institute of Technology

Dr. Bruce Stiftel
School of City and Regional Planning
Georgia Institute of Technology

Dr. Jiawen Yang
School of City and Regional Planning
Georgia Institute of Technology

Dr. Bert Bras
School of Mechanical Engineering
Georgia Institute of Technology

Date Approved: [June 21, 2011]

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SUMMARY

This study aims to demonstrate the critical role of waste management in urban sustainability, promote planners' contribution to proactive and efficient waste management, and facilitate the integration of waste management into mainstream sustainability planning.

With anticipated increases in population and associated waste generation, timely and effective waste management highlights one of the most critical challenges of sustainable development, which calls for meeting "the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Waste management in urban areas plays a particularly important role, given that waste generated from urban areas are often exported out of the region for processing and treatment, and the impacts of waste disposal activities may pass on to the other jurisdictions, and even to the next generations. An urban system cannot be sustainable if it requires more resources than it can produce on its own and generates more wastes than the environment can assimilate.

The current waste management practice, which focuses on short-term impacts and end-of-pipe solutions, is reactive in nature and inadequate to promote sustainability within urban systems, across jurisdictions, and across generations. Through material flows in and out of urban systems, many potential opportunities exist to reduce waste generation and to minimize the negative impacts on the environment, the economy, and the society. City planners' involvement in waste management, however, has been largely limited to siting waste management facilities.

Linking waste management with three important lenses in planning - economic development, land use, and environmental planning, this study investigates the impacts of urban growth on waste management activities, the need of transforming the reactive nature of current waste management, and the challenges and opportunities for planners to promote urban systems' self-reliance of material and waste management needs.

This study includes three empirical analyses to complement theoretical discussions. First, it connects waste statistics with demographic data, geographic characteristics, and policy instruments at the county level to examine whether waste volume can be decoupled from urban population growth. Second, it examines the life cycle costs of different waste management options and develops a simulation study to seek cost-effective strategies for long-term waste management. Third, it compiles evidence of geographic-specific characteristics related to waste management and demonstrates why waste management policies cannot be one-size-fit-all.

This study finds that, with successful implementation of strategic policy design, waste generation and its associated impacts can be decoupled from population and urban growth. Good lessons about waste reduction programs can be learned from different communities. Meanwhile, this study also reveals various challenges facing communities with heterogeneous characteristics, such as housing density, building age, and income. Accordingly, this study discusses the potential opportunities for planners to contribute to community-specific waste management programs, the prospect of transforming waste management practice from a cost burden to a long-term economic development strategy, and the need to incorporate waste management into the sustainable urban planning agenda.

CHAPTER 1

INTRODUCTION

Characterized as the "Material Age" and the "throwaway economy" by Brown (2001), postmodern societies have magnified vigorous and even excessive consumption of materials for convenience, comfort, and luxury. In the past half-century, the per capita municipal solid waste (MSW) generation rate in the U.S. increased over 70% (U.S. EPA, 2010). With anticipated population increase and associated waste generation, timely and effective waste management is one of the most critical challenges of sustainable development that needs to meet "the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Waste management in urban areas plays a particularly important role, given that waste generated from urban areas are often exported to rural and low-income areas for disposal, and the full impacts of waste disposal activities may pass on to many years afterwards.

As early as half a century ago, Wolman (1969) stressed the importance of proper waste management to a city in his "city metabolism" model. Wolman considered that all the materials and commodities required to build, to sustain, and to rebuild a city are components of the city's metabolism process. He argued that "the metabolic cycle is not completed until the wastes and residues of daily life have been removed and disposed of with a minimum of nuisance and hazard" (p.276).

The "nuisance and hazard" that Wolman was concerned about, unfortunately, still exists for waste management activities nowadays. Regardless of the commonly perceived pollution to the air, water, and land, landfill disposal is still the primary method of contemporary MSW management (El-Fadel et al., 1997; U.S. EPA, 2010). Of the 188 toxic air pollutants regulated under the Clean Air Act, 30 may be emitted during the waste decomposition process in landfills (U.S. EPA, 2002). In terms of methane, landfills are the largest anthropogenic source, generating one quarter of total methane emissions (U.S. EPA, 2011). In addition to air emissions, landfill leachate can contaminate groundwater that may further migrate offsite. The potential hazards to human health are significant, given that 51% of the U.S. population and 99% of the rural population rely on groundwater to meet drinking needs (Groundwater Foundation, 2005). In addition, waste collection and transportation activities generate air pollution, impair the aesthetic value of the natural environment, and increase traffic accidents. Empirical studies have shown property value depreciation in the neighborhoods adjacent to landfills (Nelson, et al., 1992; Reichert et al., 1992; Hite et al., 2001; Ready, 2005; Eshet, 2005). Therefore, landfills are frequently categorized as obnoxious facilities and locally unwanted/undesirable land uses (LULU).

Meanwhile, a former official of the Illinois Environmental Protection Agency states that "landfills and communities can work together and accept each other and actually benefit from each other" (Parker, 2003). Several cities have supported this statement claiming "garbage is good" for them (Parker, 2003). The "benefit" here refers to the host community fees, tax revenues, free or low-cost waste disposal quotas, portion of energy recovery, and infrastructure improvement. For example, several states in the U.S. (such as Georgia, Massachusetts, Maine, Minnesota, New Jersey, Pennsylvania, Tennessee, and Wisconsin) require private landfills to compensate hosting communities with at least $1 per ton of waste received (Fort and Scarlett, 1993; Jenkins, Maguire &

Morgan, 2004). These compensation mechanisms have made waste disposal facilities welcomed in some communities, especially those facing economic difficulties.

A contrasting view of landfills suggests that waste management is more than just an environmental problem. Waste material flows are associated with not only a transformation from raw materials to waste materials, but also a redistribution of wealth and socioeconomic impacts as well as environmental consequences.

In practice, waste management interacts with city planning fundamentally from the source of waste generation: people and built environment. City planners' involvement in waste management, however, has been largely limited to the environmental field, with a focus on facility siting in particular (see Lober, 1995; Hostovsky, 2000; Farhan and Murray, 2006). In other words, waste management is commnly perceived as the "end-of-pipe" of socioeconomic activities. Thus, current waste management programs have focused on disposal of the waste generated, instead of examining the sources of waste generation and the entire life cycle of waste materials and products.

In contrast, planners naturally possess the unique skills and knowledge to contribute to proactive and efficient waste management. First, planners are familiar with local and regional demographic and employment characteristics as well as its economic structure. They are adept at using local data for dynamic estimates of infrastructure and community planning, and waste management programs may naturally fit in the long-term plan. Furthermore, planners place a special focus on spatial implications of policy making and are ready to incorporate local characteristics to develop community-specific waste management policies. Additionally, planners hold a holistic view of a region and are most capable of managing the highly interdisciplinary issues of waste management. A good understanding of the complexity in waste management helps minimize the conflicts between stakeholders and planning objectives, and subsequently, promotes social equity, environmental effectiveness, and economic efficiency in waste planning.

PURPOSE OF STUDY

This study aimed to enhance the understanding (of the public and of sustainability planners, in particular) about the critical role of waste management in sustainable urban planning. This study proposed a system view of sustainable waste management that are environmentally responsible, socially accountable, and economically efficient. In particular, this research aimed to demonstrate the need of incorporating the long terms impacts of waste management activities into waste planning process. The current practice of waste management has primarily focused on the short-term impacts, such as economic cost and environmental pollutions to the air, water, and land. It is the less tangible and long-term impacts, such as post-closure care, uncertainties in long term impacts, regional self-reliance of material and waste management, that present greater challenges to urban sustainability. Employing both theoretical and empirical research methods, this research investigated how planners may play a proactive and effective role in promoting sustainable waste management that addresses both short-term and long-term impacts, as illustrated in Figure 1.1.

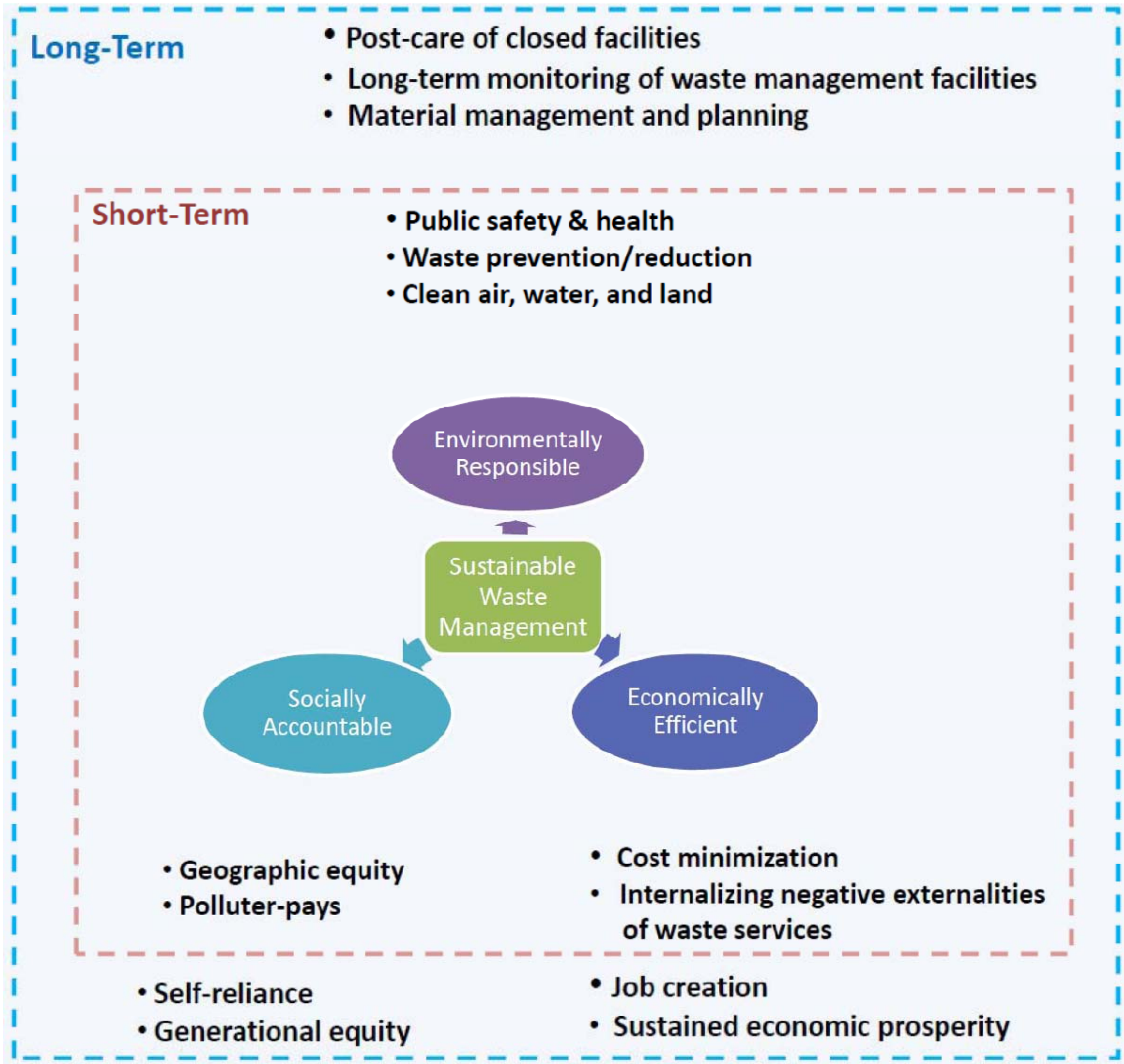

Figure 1.1: Goal Definition for Sustainable Waste Management

RESEARCH QUESTIONS

Linking waste management with three important lenses in planning-land use, economic development, and environmental planning, this study investigated the impacts of urban growth on waste management activities and potential strategies to promote sustainable waste management. In particular, this study discussed why the reactive nature of current waste management needs a transformation, how planners may contribute to sustainable waste management planning, and the challenges as well as opportunities that planners should address to promote the self-reliance of urban systems' waste management needs.

To complement theoretical discussions, this study included three empirical analyses. First, it connected waste statistics with demographic data, geographic characteristics, and policy instruments at the county level to examine whether waste volume can be decoupled from urban population growth. Second, it examined the life cycle costs of different waste management options and develops a simulation study to seek cost-effective strategies for long-term sustainable waste management. Third, it compiled evidence of geographic-specific characteristics related to waste management, and demonstrates why waste management policies cannot be uniform across all regions.

SCOPE OF STUDY

The empirical analysis of this study focused on the U.S., with the special concern that its per capita waste generation rate is higher than many other advanced economies and the magnitude of difference is even bigger when compared to developing countries (Giusti, 2009). Previous studies in other countries are included in the literature review and theoretical discussions, mainly for evaluating the external validity of this research and for seeking opportunities of mutual learning across regions and countries.

There is no single categorization or standard definition of waste. Generally speaking, waste can be solid or liquid. Further, waste can be categorized by the generator, such as residential, commercial, and industrial sectors. Non-hazardous solid wastes generated from residential and commercial sectors, as well as some industrial sectors, are loosely defined as municipal solid waste (MSW). In addition to MSW, there are other types of waste, such as hazardous industrial waste, medical waste, and nuclear waste.

MSW was selected as the focus of this study for several important reasons. First, MSW and hazardous industrial wastes are regulated differently by legislation and processed through different systems. The variance in waste characteristics and management methods determines that different types of waste need to be examined separately, although policy implications in general can be applicable to all. Second, MSW management necessitates more attention from both the public sector and individual households. The common flat-rate garbage fees have made waste management “out of sight, out of mind,” regardless of the volume generated. In addition, hazardous wastes (such as batteries, light bulbs, and computers) from households are still under-regulated and may incur higher costs for future remediation when they are mixed in the MSW stream. Third, MSW management is traditionally a public service but the private sector has played an increasing role (Waste Business Journal, 2009). Currently the advantages and challenges of privatizing MSW management have not been carefully examined. Thus, policy insights are critically needed to determine what role public sector should play for sustainable MSW management and planning.

SIGNIFICANCE OF STUDY

This study enhances planners’ awareness and understanding of the interactions between waste management and urban planning, promotes planners’ contribution to sustainable waste management planning, and facilitates integration of waste management into mainstream planning in order to promote urban sustainability. In particular, this research promotes a system view of waste management and demonstrates the application of interdisciplinary tools in urban sustainability analysis.

STRUCTURE OF STUDY

This dissertation begins with a background introduction of waste management in Chapter 2, reviewing waste generation volume, pertinent regulations, management methods, and ensuing impacts. Chapter 3 reviews multidisciplinary literature surrounding urban sustainability, and discusses why sustainable waste management planning is needed from a theoretical perspective. Chapters 4 to 6 extend the theoretical discussions with empirical analysis. Specifically, Chapter 4 employs panel data analysis to investigate whether waste generation volume can be decoupled from urban growth, and if yes, what factors may play a role. Chapter 5 presents a simulation study in California to investigate the cost effectiveness of different waste management options in the long run. Chapter 6 focuses on the impacts of geographic characteristics on waste management, and discusses why one-size policy cannot fit all in terms of waste management. Each chapter includes its specific research hypotheses, literature review, research methods, data collection and analysis, results and discussions. Chapter 7 summarizes the research findings and discusses the policy implications for planners to contribute to sustainable waste management and urban sustainability in general.

CHAPTER 2

STATUS OF MUNICIPAL SOLID WASTE MANAGEMENT

Meaningful and effective waste management policy design first necessitates a good understanding of the current practice and challenges. This chapter provides an overview of the status of waste management in the U.S., in terms of waste generation volume, pertinent regulations, management methods, and ensuing impacts. It concludes with discussions about the challenges of current waste management practice for urban sustainability.

WASTE GENERATION VOLUME

Economic prosperity has been historically associated with abundance in products and materials for consumption. Since economic growth is measured as a sustained increase in production output and expenditure, it is not a surprise to see that waste generation volume has increased along with economic growth in the past half-century. In the U.S., annual municipal solid waste (MSW) generation had steadily increased from 88 million tons in 1960, to 243million tons in 2009 (U.S. EPA, 2010). As illustrated in Figure 2.1, the per capita MSW generation rate is positively correlated to the per capita gross domestic product (GDP), although the correlation appears to have weakened considerably in the recent decade (U.S. EPA, 2010; U.S. Department of Commerce, 2009). The trend would be even more striking if the amount of waste were to be measured in units or volume, instead of weight, considering that many packaging materials in the waste stream have changed from glass to much lighter-weight plastic and paper.

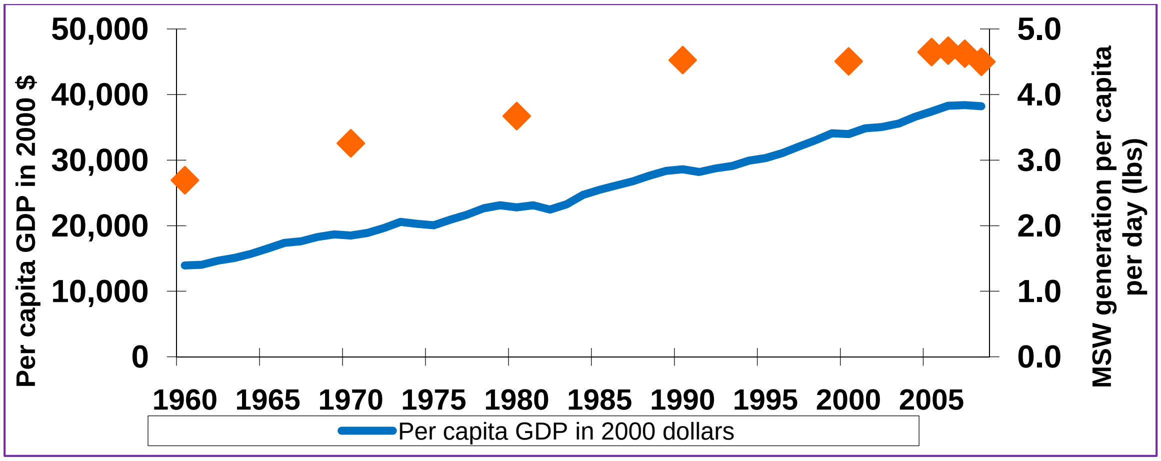

Figure 2.1: Per Capita GDP and MSW Generation in the U.S. (1960-2009)

Sources: (1) U.S. EPA. (2010B). Municipal Solid Waste in the United States: 2009 Facts and Figures. (2) U.S. Department of Commerce. (2006). News Release: Gross Domestic Product by Industry.

In comparison to other countries, the annual per capita waste generation rate in the U.S. is the highest among advanced economies and is almost five times as much as that in China, as shown in Figure 2.2 (Giusti, 2009). The data suggests that the U.S. production and consumption experienced higher intensity and generated greater impacts than other countries, but it did not necessarily have to be in order to achieve similar rate of economic growth.

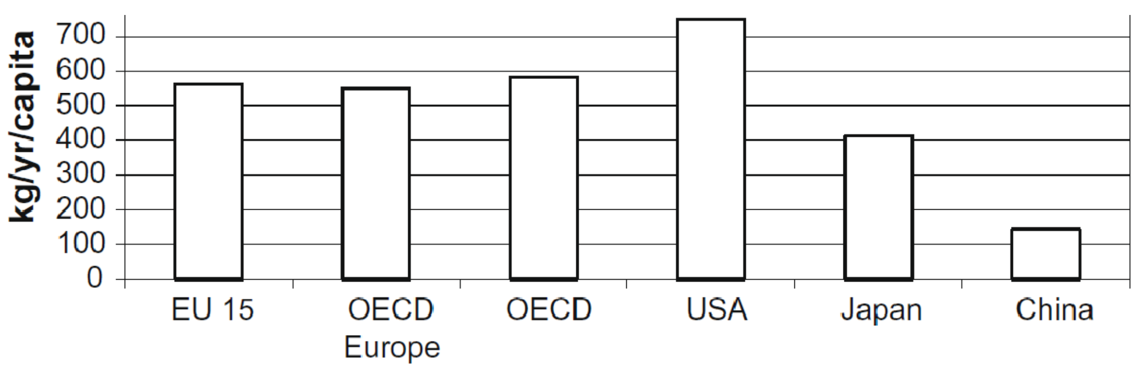

Figure 2.2: Per Capita MSW Generation Rate Comparison across Countries

Source: Giusti, L. (2009). A review of waste management practices and their impact on human health. *Waste Management,* 29, 2227-2239.

PERTINENT WASTE MANAGEMENT REGULATIONS

Municipal solid waste management is mainly regulated by five federal legislations (Foster and Repa, 2002). The legislation that has the primary focus on waste management is the Solid Waste Disposal Act (1965) and its 1976 Amendment - Resource Conservation and Recovery Act (RCRA). This 1976 amendment is so comprehensive that the Solid Waste Disposal Act has been frequently referred to as RCRA. RCRA regulates both hazardous (Subtitle D) and general waste (Subtitle C) in terms of waste generation, transportation, treatment, storage, and disposal. Regulations for water treatment, storage, and disposal (TSD) are the most onerous, whereas waste transportation seems to be the most loosely regulated (Salzman, 2003).

In addition, Clean Air Act (CAA) controls emissions from both waste transportation and incineration facilities, Clean Water Act (CWA) prohibits pollutant discharge into navigable water bodies, and Federal Aviation Administration (FAA) provides guidance to prevent bird-aircraft collisions in the vicinity of airports (Foster and Repa, 2002).

Because waste management services share similar characteristics of traditional service sectors, waste transport has been regarded as a trade activity with "wealth" transfer. Therefore, waste management is also regulated by the Interstate Commerce Clause, which protects interregional waste flow domestically and prohibits discriminations of waste simply by their origin (Macauley, 2009).

While federal regulations (such as the RCRA Subtitle D) require all states to implement plans to maximize waste reduction and recycling, the efforts at the state and local levels vary greatly. In the particular case of household waste, which accounts for

55 to 65 percent of MSW, is still under-regulated in the U.S. (U.S. EPA, 2010). Up to present, there is no U.S. federal regulation that mandates residential recycling. Many states and local communities have undertaken voluntary initiatives to adopt the most preferred methods and established education and recycling programs. As of 2006, it is estimated that 8,660 curbside recycling programs operated in the U.S. (Biocycle Magazine, 2006). Generally speaking, regions in the west coast and in the northeast play a leading role in environmentally proactive policy-making and have voluntarily enforced stringent standards beyond federal regulations.

The State of California, in particular, is a national leader in proactive waste management. Upon the enactment of RCRA, the State created the Solid Waste Management Board upon the enactment of RCRA, developed curbside recycling infrastructure at an early stage, and set stringent requirements for new landfills in terms of life cycle considerations. California's proactive and progress regulations have been even more stringent than the federal standards, and thus won its authority over its own solid waste management (California Integrated Waste Management Board, online information).

For many other regions, although waste reduction and recycling goals were well expressed, there were actually no "enforceable measures" and consistent support to reach its targets at the due time (Goldstein & Izeman 1990, p. 20; Phillips, 1998; Tchobanoglous, Keith, and Williams, 2002). The following sections below discuss in more details how the policy framework as well as the environmental and economic characteristics of waste management has shaped the current paradigm of waste management practice in the U.S.

WASTE MANAGEMENT METHODS

After MSW is collected, there are mainly three outlets as illustrated in Figure 2.3. Most of waste is condensed and baled at the transfer station, and loaded into larger trucks destined to be buried (in landfills) or for combustion (in incinerators). Some incinerators have installed waste-to-energy technology, for reuse of the energy from waste combustion. Recyclable materials, either sorted at the source of generation, or at material recovery and processing facilities, are processed for resell or remanufacturing. The contaminated recyclables and non-recyclables that are mingled in the recycling stream, are transported to waste disposal facilities. The third outlet of waste management, composting, which is mostly adopted to process yard debris and food residuals, had limited application in cities but received increasing attention in recent years.

Based on the environmental impact assessment of each waste management method, the U.S. EPA suggests a solid waste management hierarchy (Figure 2.4); the landfilling and incineration are the least preferred method, and source reduction and reuse are the most preferred method followed by recycling and composting (U.S. EPA online information).

In practice, the least preferred methods of landfill disposal and energy recovery by combusting the waste have been the destination for 66% of the total waste stream in the U.S. (U.S. EPA, 2010). Recycling and composting have received increasing application compared to decades ago, as shown in Figure 2.5. However, the national recycling rates experienced little growth in the past decade. In 2009, the latest data is available, 34% of MSW was recycled, compared to 29% in 2000 (U.S. EPA, 2010).

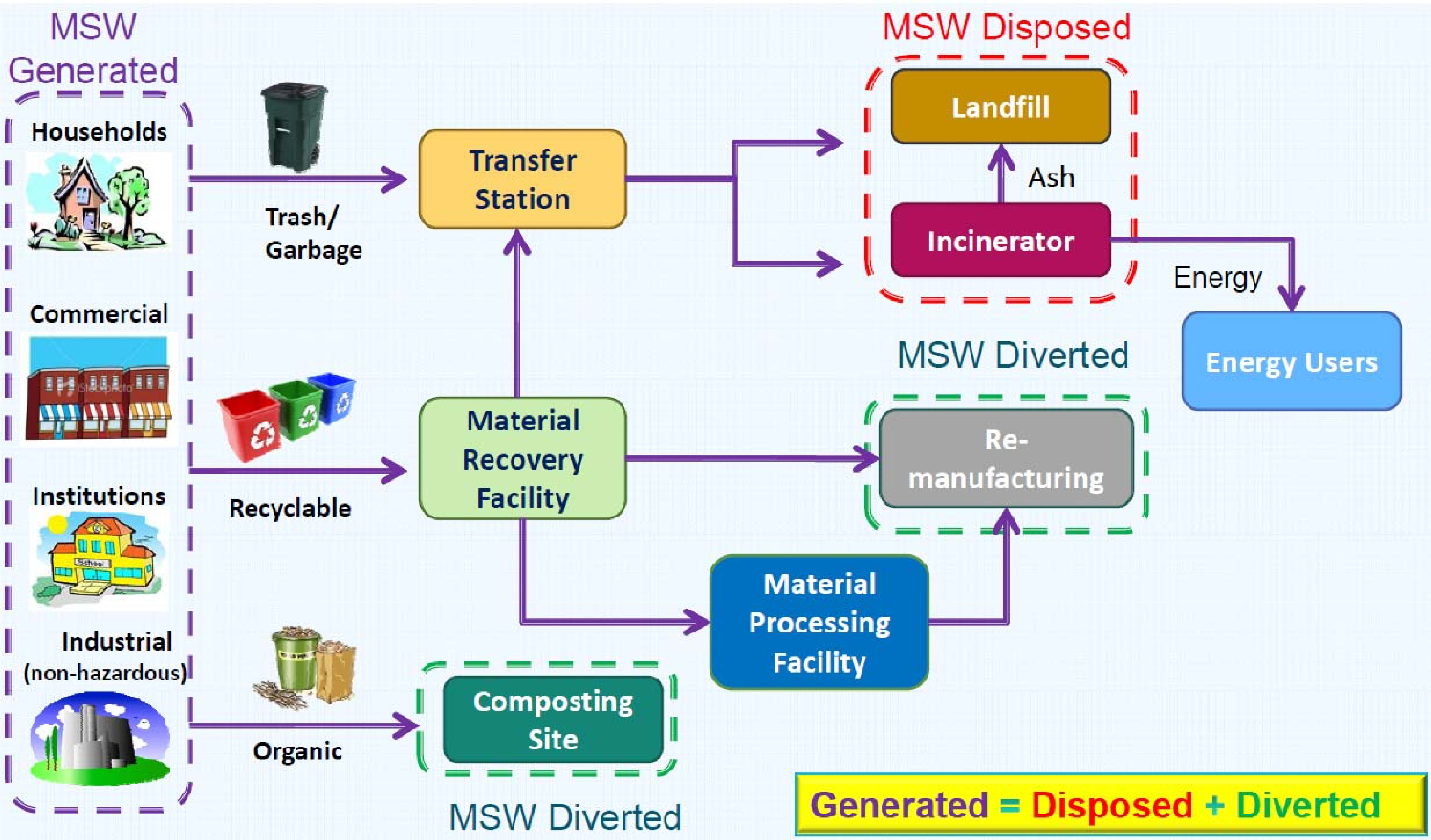

Figure 2.3: Municipal Solid Waste Flow

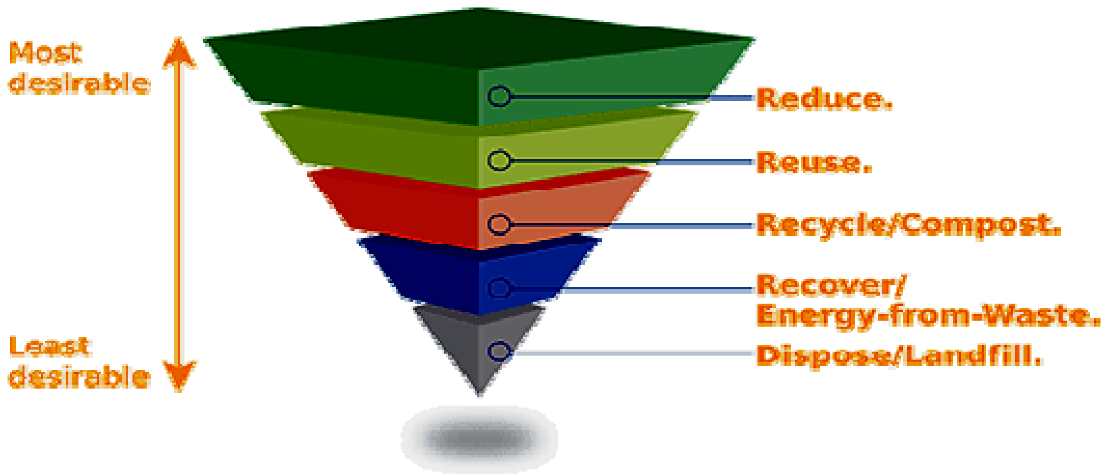

Figure 2.4: Solid Waste Management Hierarchy

Source: http://cm3.missiondata.com/uploads/28/Image/waste-hierarchy-pyramid.gif

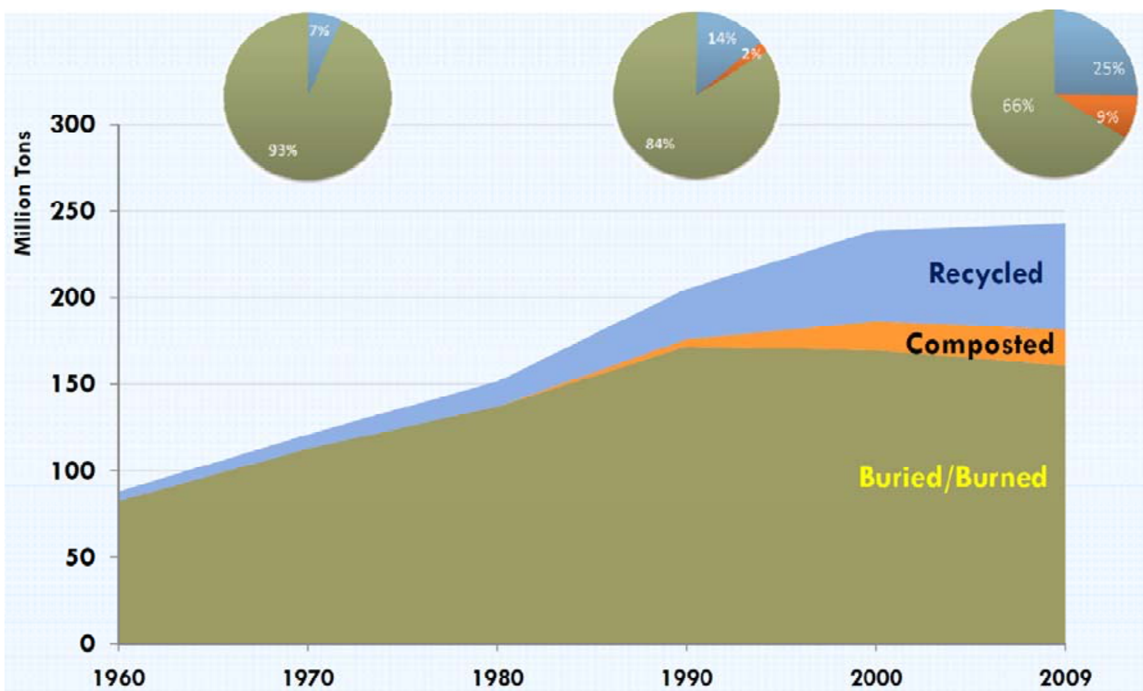

Figure 2.5 MSW Management Method 1960-2009

Source: U.S. EPA. (2010B). Municipal Solid Waste in the United States: 2009 Facts and Figures. Charts are made by the author.

Meanwhile, although waste management legislations and regulations have been continuously evolving, the changes have been mainly developed as post-crisis solutions, instead of pollution prevention strategies. Table 2.1 below provides an example in terms of landfill design. Waste management technology was often chosen as the least cost option, and lasted until the system failed (Tammemagi, 1999; Lee and Lee, 2004).

Table 2.1: Evolution of Landfill Design Development

Problems	Time	Landfill design development
Health/Nuisance; odors, windblown refuse, open and uncontrolled fires, insects	1950s	Daily cover, better compaction, soil-clay liner
Groundwater contamination by leachate through soil-clay liner	1970s	Plastic sheeting (HDPE) liner
Relatively small holes in HDPE liners led to high leakage rates; air emissions	Mid 1980s	Composite liners/covers, leachate and gas collection systems
Isolation of landfill design with surrounding environment	Late 1980s	Incorporation of technical, socio-political factors into siting process

Sources: Summary from (1) H Tammemagi, H. (1999). *The Waste Crisis: Landfills, Incinerators, and the Search for a Sustainable Future*. New York/Oxford: Oxford University Press. (2) Lee, G. F. and Jones-Lee A. (2004). Overview of subtitle D landfill design, operation, closure and post –closure care relative to providing public health and environmental protection for as long as the wastes in the landfill will be a threat. Online publication at [http://www.gfredlee.com/Landfills/LFoverviewMSW.pdf].

Again, because of economic considerations, jurisdictions may export their waste out of their jurisdictional boundary for disposal, when the total of transportation costs and waste disposal fees in other regions present a cost saving than managing it on its own. Jurisdictions may also accept waste generated from other regions for revenues gained from economies of scale. As discussed earlier, inter-state waste transfer is protected by federal regulations. Many regions both import and export waste, as those shown with double arrows in Figure 2.6. While many transfers are across adjacent counties or states, some could be across the nation or continents. Some states, such as Pennsylvania, Virginia, Michigan and Oregon, import significantly higher volume of waste from other regions than its imports, and thus present a large net waste import volume on a per capita basis (Figure 2.7). Economic considerations have resulted in an uneven distribution of waste destination compared to waste origin. More details are discussed in the following section about the economic characteristics of waste management.

ENVIRONMENTAL IMPACTS OF WASTE MANAGEMENT

The environmental impacts of MSW are associated with not only its enormous volume but also its toxicity. Although MSW are generally considered non-hazardous wastes, toxic materials in the MSW stream, such as batteries, paints, inks, lamps, and fabrics, are common. As explained in Table 2.2, many of them contain carcinogenic substances that and may present risks to human health if not managed properly (Table 2.2) The percentage of toxic materials in the MSW has increased in the past decades after synthetic materials became widely manufactured, consumed, and discarded (Geiser, 2002).

The toxic materials, if mingled with other non-hazardous waste in the MSW stream and ended in landfills, generate the greatest impacts on the environment through the life cycle, compared to all the other waste management options (see Denison, 1996; El-Fadel et al., 1997; Morris, 2005).

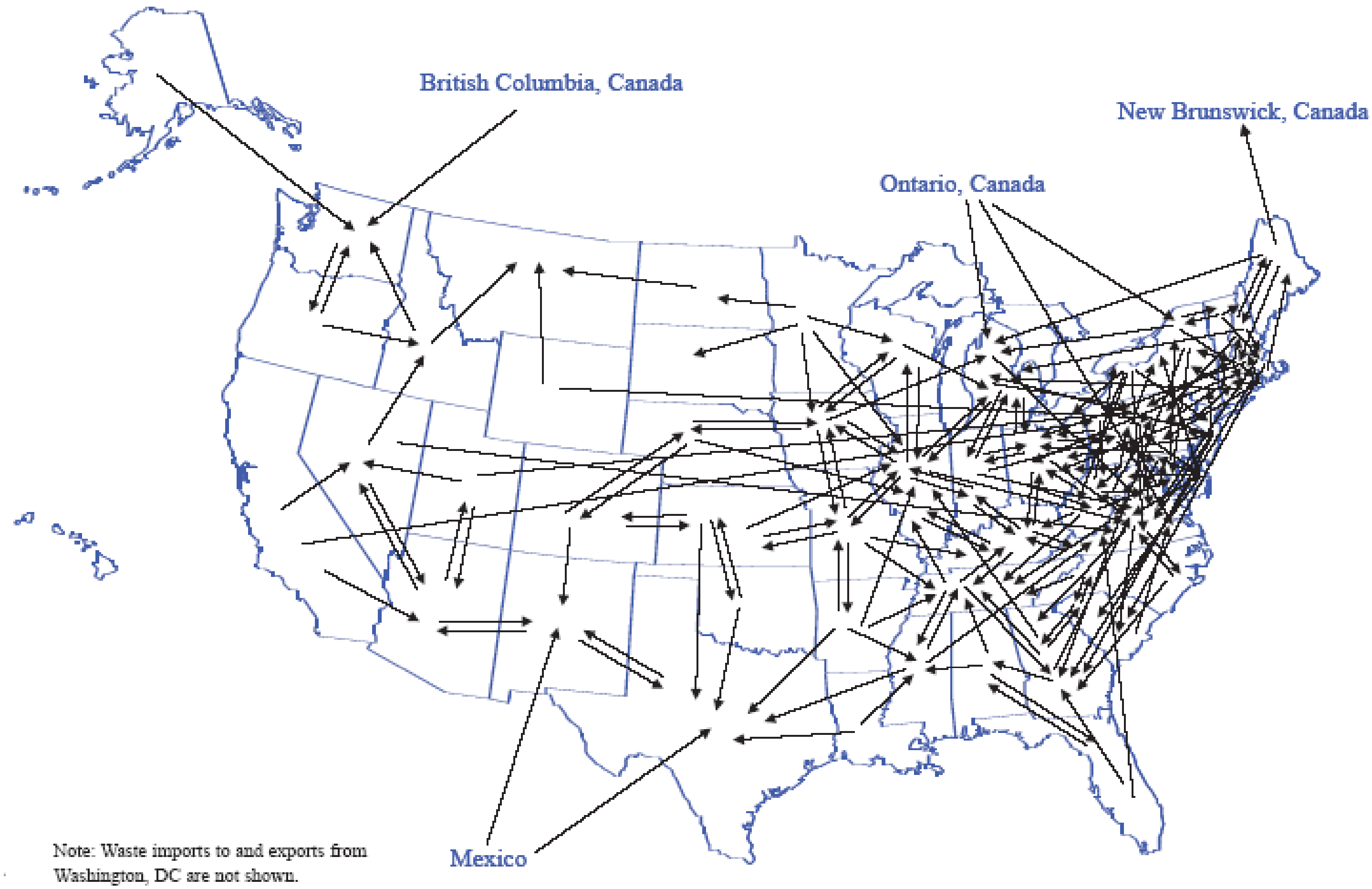

Figure 2.6: Interstate Waste Movement 2003

Source: National Solid Waste Management Association (NSWMA). (2005). Research Bulletin 05-02. [http://www.nswma.org/InterstateWaste2005.pdf]

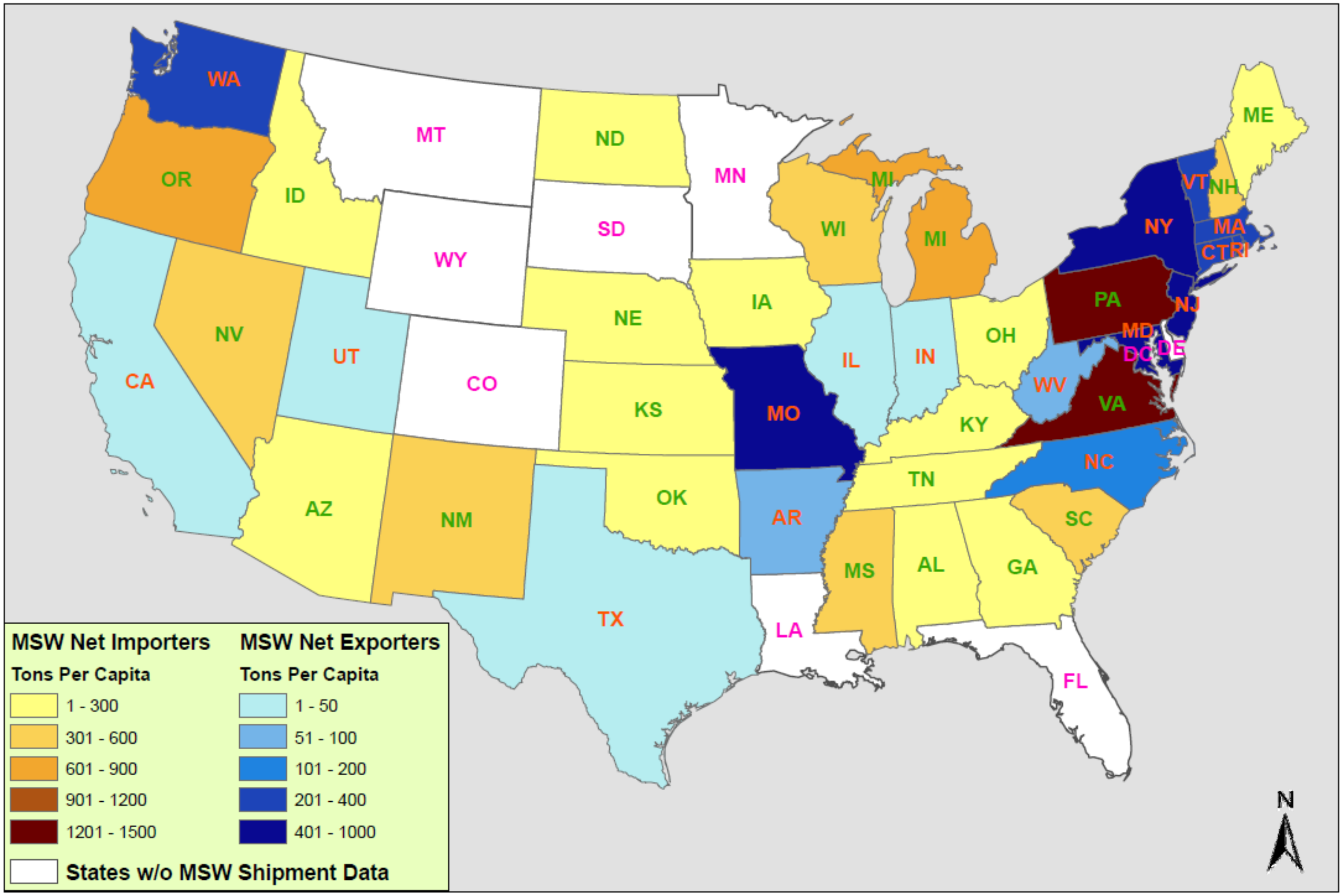

Figure 2.7: Per Capita MSW Net Import and Net Export by State in the U.S. (tons)

Source: Map by the author using data compiled by Congressional Research Service. (2004). Interstate Shipment of Municipal Solid Waste: 2004 Update.

Table 2.2: Common Toxic Materials in Municipal Solid Waste

Substance	Sources	Health effects
Cadmium	Batteries, inks, paints	Carcinogen, ecotoxin, reproductive effects
Lead	Batteries, varnishes, sealants, hair dyes	Neurotoxin, reproductive effects
Mercury	Batteries, paints, fluorescent lamps	Ecotoxin, neurotoxin, reproductive effects
Methylene chloride	Paint, paint strippers, adhesives, pesticides	Carcinogen
Methyl ethyl ketone	Paint thinner, adhesives, cleaners, waxes	Neurotoxin, reproductive effects
Perchloroethylene	Rug cleaners, spot removers, fabrics	Carcinogen, ecotoxin, reproductive effects
Phenol	Art supplies, adhesives	Ecotoxin, developmental effects
Toluene	Paint, nail polish, art supplies, adhesives	Ecotoxin, mutagen, reproductive effects
Vinyl Chloride	Plastics, apparel	Carcinogen, mutagen, reproductive effects

Source: Geiser, K. (2002). Source Reduction: Quantity and Toxicity Part 6B: Toxicity Reduction. In Handbook of Solid Waste Management (2nd Edition), edited by George Tchobanoglous and Frank Kreith. New York: McGraw-Hill Companies, Inc.

As early as the 1980s, NYC DOS has reported that the concentration of some toxic materials in waters near landfills was up to 100 times higher than state standards. Contaminants detected in adjacent waters included mercury, lead, nickel, PCBs, cadmium, benzene, trichloroethylene, chromium, and other organic compounds (Goldstein & Izeman, 1990). To remove these contaminants, physical /chemical /biological processes may be needed. Some contaminants may need even more advanced removal techniques (see Reinhart &Grosh, 1998).

As scientists still do not have the full-scope knowledge of potential risks of landfills, no one could really predict what problems may arise from closed landfills. For some closed landfill sites for which contamination has yet to be detected, such as the Edgemere landfill, the public is still fearful of the potential risk from more than 3,000 drums of toxic materials illegally buried there (Goldstein &Izeman, 1990). Uncertainties lie in the redevelopments of these waste treatment facilities, in terms of it potential risks that are not immediately tangible or measurable.

Yet, the socioeconomic and environmental impacts of waste disposal facilities only represent the end-of-pipe impacts of waste management. The chain of activities, including raw material extraction, manufacturing, consumer use, disposal, and transportation through the life cycle of products and materials, all generate footprints on the environment (Figure 2.8). Local waste management practice has increasingly generated global impacts.

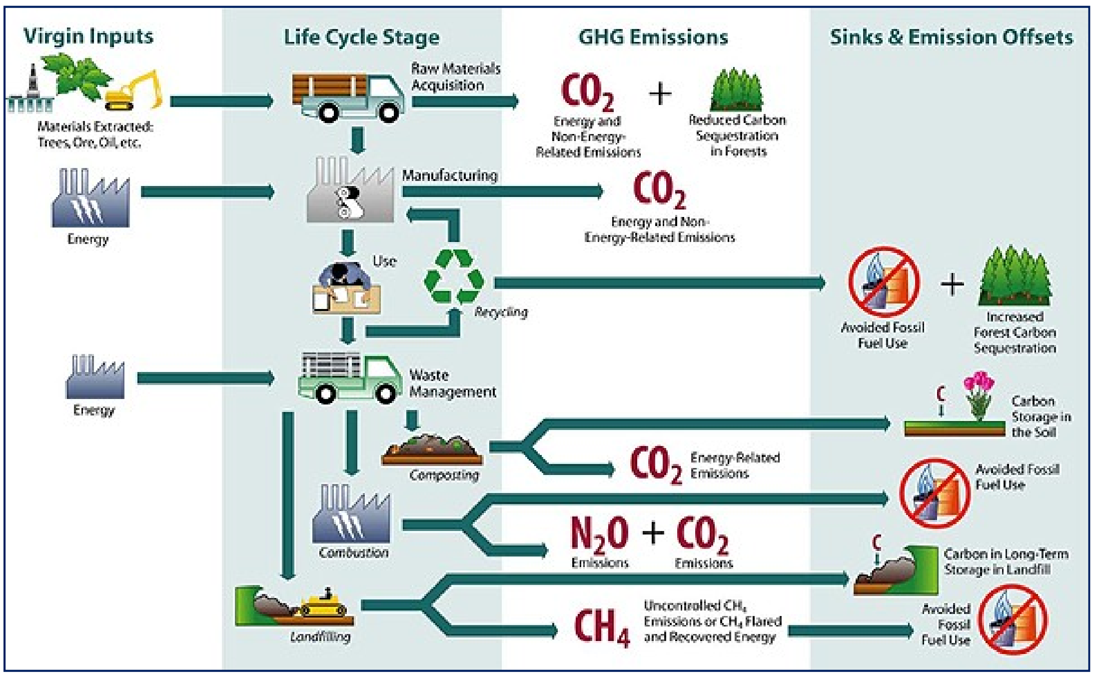

Figure 2.8: Life Cycle of Waste Management

Source: U.S. EPA. (2002) Life-Cycle of Waste Image and Description. Online publication at [http://www.epa.gov/climatechange/wycd/waste/lifecycle.html]

In contrast, recycling and reuse may reduce the use of raw materials and energy, and minimize the footprint of production and consumption. However, it has only achieved limited success in the U.S. As demonstrated in a cost-benefit analysis of waste management options (Ai, 2006), waste management policies are largely designed on the basis of economic considerations. Thus, economic characteristics of waste management from an economic sector’s perspective deserves a careful study.

ECONOMIC CHARACTERISTICS OF WASTE MANAGEMENT

The increasing volume of waste contributed to the significant growth of the waste management industry. Waste Management and Remediation Services is an economic sector that is formally identified in the U.S. Economic Census. The sector had 366,780 employees and generated over $73 billion of revenue in 2007 (U.S. Department of Commerce, 2009). Compared to a decade ago, the sector's employment has increased about 30%, while the industry revenue has almost doubled. The sector has experienced much faster growth than the average growth rate of the national economy.

Like many other industries, the waste industry experiences typical economies of scale. Prior to operation, initial investment in a waste processing or disposal facility typically involves a high fixed cost (e.g., for land purchase and facility construction) and capital compliance cost (e.g., for compliance determination, initial permission and monitoring). The time, efforts, and resources to remove public opposition, in many cases, added to the initial cost of landfill construction, if successful at all. Waste facility operation cost, however, does not increase proportionately with waste disposal volume. The National Solid Waste Management Association estimated that the average unit cost of a typical municipal landfill declines by about 70 % as its capacity increases from 250 to 3,000 tons per day (NSWMA 2001; Delong, 1994).

Second, new entry into the waste management market can be deterred by increasingly stringent regulations that are often developed to address environmental problems that appear over time (Beede and Bloom, 1995). As noted earlier, solid waste management are mainly regulated by several federal legislations, such as federal Resource Conservation and Recovery Act (RCRA), which specify the requirements of location, scale, number and technology application of waste disposal facilities. Regulations in regions with limited supply of land resources, such as the Northeast and West Coast, are typically more proactive than that at the federal level. Prohibitive compliance cost have essentially prevented the start-up of small landfills and forced small landfills to close.

Third, the process of landfilling itself is not labor intensive; land resource is the dominant production factor in landfilling activities. In other words, the cost of landfill disposal can be heavily dependent on its location, which partially explains the variance in waste disposal fees across regions. A landfill's location can also determine its accessibility to waste haulers, in terms of both transportation distance and mode. Many landfills are located close to county or state boundaries, so that they may help maximize input by accepting waste from multiple jurisdictions. Further, because rail and barge transport is cheaper than truck hauling, the availability of rail or water access is an advantage for landfill operation. For example, landfills in Virginia have been substituted for those in Pennsylvania as the destination of waste generated in New York, because New York recently changed waste transport mode from road to rail and the landfills in Pennsylvania lack access to rail (McCarthy, 2007).

Lastly, both market forces and waste management legislations have led to concentration and consolidation in the waste industry. The previously discussed Interstate Commerce Clause has provided flexibility in inter-regional waste flow for the least-cost options of waste disposal, and subsequently, facilitated the formation of regional centers of waste disposal, such as Pennsylvania, Virginia, Michigan and Oregon (Figure 2.6). The consolidation of waste disposal activities has also been influenced by (and resulted in) the universal increase in disposal fees. The consolidation trend can be also evidenced by the statistics of waste disposal facilities. Nationwide, while the total number of landfills steadily decreased from about 8,000 two decades ago to 1,812 in 2008, the average landfill capacity increased from an approximate average of 11 years to over 16 years (U.S. EPA, 2009; Repa, 2000). Waste management activities have also experienced vertical consolidation, integrating multiple waste streams and a chain of waste services into a unified management structure. In 2002, the top four solid waste management firms accounted for 64 % of the receipts of the entire industry (U.S. Department of Commerce, 2004). In 2008, the second and third largest waste companies (Allied Waste and Republic Services) further achieved a $6.59 billion merger to combat the economic downturn and rising fuel costs (Delaney, 2008). As Gandy (2002) noted, "the waste management industry has been changing from a dominance of family-run small firms with local or regional monopolies towards a new generation of powerful international corporations that can offer greater economies of scale and new sources of technical expertise" (p.213).

Given the economic characteristics discussed above, it is evident that merger activities can reduce the unit cost of waste management by taking advantage of existing infrastructure and equipment. Streamlined services may reduce the transaction costs along the service chain of waste collection, transportation, processing, and disposal. Consolidated waste industry can also help internalize the cost incurred by market fluctuations, especially given the decreasing land resources to bury waste and the rising opposition from the public to build new facilities. Without public policy intervention, an oligopolistic pattern of waste management will continue and perhaps strengthen.

The potential changes in waste management market structure have two economic implications. On the one hand, oligopoly generates economies of scale and may lead to increasing efficiency of waste management in general. On the other hand, oligopolists may gain dominant control of the market and raise the price of waste management, which is largely price inelastic due to the need for timely treatment on a routine basis. In fact, historical trend data already suggest that all regions may face increasing cost for waste disposal and the discrepancy of landfill disposal fee may continue to diminish in the future. In the past two decades, the national average landfill disposal fee (tipping fee) steadily increased, while the variance of regional tipping fees compared to the national average (measured by standard deviation) decreased (Figure 2.9). Further, the oligopolistic pattern may boost certain waste management methods (e.g., landfilling) as well as discourage others (e.g., recycling), especially when landfill disposal activities have achieved economies of scale while recycling markets are still unstable.

Meanwhile, regulatory factors may play an important role in diversifying the waste management industry, and thereby, counteracting the tendency of oligopoly. For example, a future ban on more types of materials (e.g., carpets, computers, and yard wastes) from landfills would result in more complexities in waste collection and processing. One single firm may find it increasingly difficult to manage the variations in waste characteristics across different regions. Thus, the waste market would not be very likely to generate a pure monopoly. In addition, local legislations may restrict the treatment of MSW within its boundary and prohibit exporting it to other regions, so that its own waste disposal facilities may operate at an efficient scale (Peretz, 1998). Implementing environmentally conscious design could alter the waste stream composition, and, consequently, the entire waste management pattern. Essentially, both private and public sectors' initiatives may lead to cost savings in waste management, but their implications can be different in terms of the distribution of net benefits.

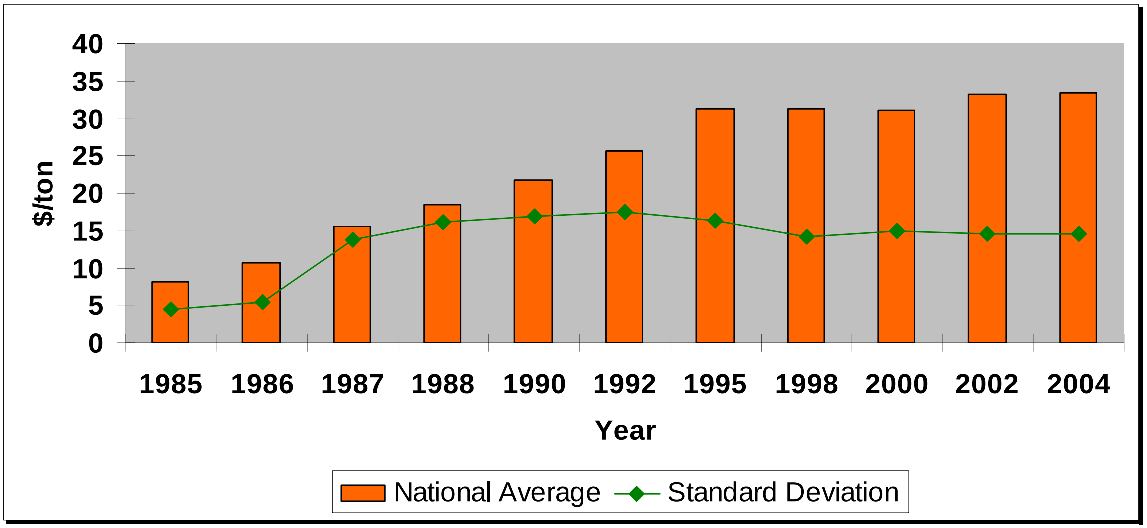

Figure 2.9: Landfill Tipping Fees in the U.S. (1985-2004)

Source: The national average data is provided by the National Solid Waste Management Association (Repa, 2005). The standard deviation value is calculated by the author.

WASTE MANAGEMENT AND URBAN SUSTAINABILITY: GENERAL EVALUATION

Waste management activities highlight the challenges that each city faces to achieve sustainable development. Since urban activities continuously generate wastes and existing technology still cannot help a region achieve zero-waste operation in the immediate future, cities mostly export the waste to other peripheral regions, frequently in the low-income and minority neighborhoods, where land is cheap and public oppositions are relatively low. Waste generated in developed countries may also travel a long way and end up in developing countries, where environmental regulations are loose and labor costs to process the waste materials are low. Eventually, waste generated by the present generation passes on the hazards to the future generations. Thus, waste management activities potentially create social inequity across both jurisdictions and generations.

Although waste management legislations have been increasingly stringent, they tend to focus on limited factors of environmental impacts only. For example, the impacts of waste hauling, although significant, are not adequately evaluated and regulated in contrast to the stringent standards of waste disposal and treatment. This gap essentially creates an incentive for long-distance hauling of wastes across regions and consequently generates environmental and social externalities. Since wastes can still be “out-of-sight and out-of-mind,” the current waste management paradigm cannot effectively promote waste reduction in the first place.

In addition, most of waste management policies have only focused on the immediate, local, and short-term effects on the environment. Inadequate attention has been paid to historical problems resulted from closed facilities, life cycle management of waste management facilities, potential risks generated from current landfilling practice, and the spill-over effects of waste export in adjacent regions (both domestic interstate-export and international transportation). Consequently, the potential impacts of waste management activities are not fully incorporated in the cost-recovery mechanism in the long run. Sustainable waste management practice needs to have a system view of waste management activities. For a city to achieve sustainability, waste reduction should be a foremost and continuous goal, instead of focusing merely on removing waste from its origin.

To promote sustainable waste management, however, policy makers need to develop financially viable solutions first. Since the current pricing mechanism does not internalize all the negative externalities of waste disposal, recycling incurs higher unit cost compared to the options of landfilling or combustion. The disadvantage in operation cost, plus the initial costs of developing a recycling system, have made recycling less competitive in many communities in the short term. Further, current waste management policy essentially creates an economic incentive for waste transfer across regions, when the total cost of waste hauling and disposal is lower than the cost of managing the waste within the region. The distorted market price only impedes recycling as well as other environmentally conscious systems of waste material management.

Finally, waste management in urban areas is particularly challenging and important. In the U.S., 80% of the population, 81% of firms and 85% of employment is located in metropolitan regions (U.S. Census, 2000 & 2002). Urban regions are the "keys to the delivery of sustainable development due to the considerable opportunity for increased quality of life through economic, political and social progress" (Low et al., 2000; Walton, 2005). The significant and growing fraction of population, material and energy flows are associated with the use and disposal of products and materials worldwide (Leigh et al., 2008, 2010). A city cannot be sustainable if it generates more waste than it can assimilate; waste reduction is more critical than waste disposal management as the end problem.

CHAPTER 3

WASTE MANAGEMENT AND SUSTAINABLE URBAN PLANNING: THEORETICAL DISCUSSIONS

"Planning is intervention with an intention to alter the existing course of events. The timing and legitimacy of planned intervention therefore become questions central to planning theory: Why and in what situations should planners intervene?" (Campbell and Fainstein, 2003, p.6).

In response to the challenges of sustainable waste management discussed in Chapter 2, this chapter connects waste management with theories pertinent to sustainable urban planning and discusses why public intervention is needed for sustainable waste management. Theoretical discussions here focus on four themes of theories related to urban sustainability: planning, urban systems, environmental economics, and regional economic development. The last section discusses the implications of ignoring the externalities of waste management in policymaking.

PLANNING FOR THE PUBLIC INTEREST

Different from corporate or individual decision-making, the planning theories discussed here are for public interest, and thus, seeks socially rational decisions. Multiple paradigms of planning can be applicable to waste management planning, as discussed below.

In a rational comprehensive model, planners identify all the alternatives that may achieve the predetermined “ends”, develop indices to evaluate each alternative in terms of goal-achievement efficacy, and finally select the “optimal means’’ to achieve the most valued ends (Altshuler, 1965, p.196; Meyerson and Banfield, 1955, p. 314; Stuart, 1969, p. 152). The iterative processes of rational planning are illustrated in Figure 3.1.

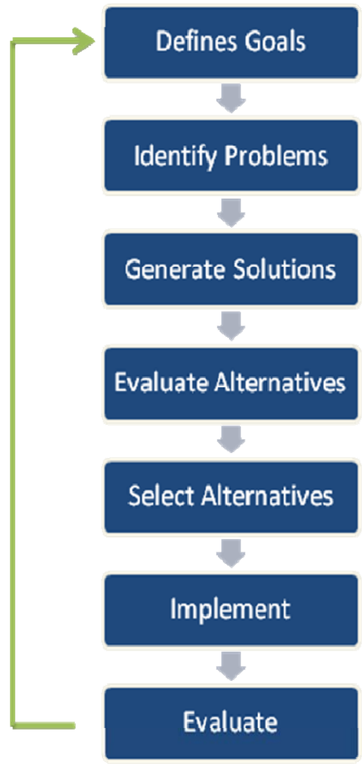

Figure 3.1 Rational Planning Processes

In comprehensive planning, planners view the public interests from an overall approach and assume that there are only one single set of uniform pubic interests. Planners assume that various collective goals can be weighted and integrated into a single hierarchy of community goals (Altshuler, 1965). In other words, the “ends” of planning can be well determined in comprehensive planning. To evaluate and select a most efficient “means’ to achieve the “ends”, Simon (1945) first formulated the “rational” model and then Meyerson and Banfield (1955) introduced it into planning literature (Faludi, 1987, p. 28). In short, comprehensive rationality maximizes the efficiency of goal-achieving performance.

As Schön (1983) argues, the rational model follows a process of “problem solving”, which assumes that “problems of choice or decision are solved through the selection, from available means, of the one best suited to established ends” (pp. 39-42). In reality, however, planning process may involve “uncertainty, uniqueness, instability, and value conflict” that generate bounded rationality for planners. Planners do not have “a well-defined problem, full array of alternatives to consider, full baseline information, full information about the consequences of each alternative, full information about the values and preferences of citizens, and fully adequate time, skill, and resources” as discussed by Forester (1984, p. 23-24). In addition, various community goals cannot be evaluated and weighted and transformed into a single perspective, which contradicts the most fundamental assumption in “comprehensiveness” in terms of “public interest” (Stuart, 1969). Thus, the rational planning processes only serves as an ideal model.

To develop solutions using incomplete information and limited alternatives, Lindblom (1979, 2003) proposed incremental planning and Bryson and Delbecq (1979) proposed a contingent approach that determines the range of choices contingent on situation changes. The difference between rational comprehensive model and incremental models, in the opinion of Faludi (1973), is merely in the degree of comprehensiveness. In essence, Faludiregards rational comprehensive models as the core of “theory of planning” (procedural theory), which focuses on planning process, or how planning operates and how planners understand themselves. In contrast, incremental models provide the basis for “theory for planning” (substantive theory), which focuses on a specific area of planning of planners’ concern. It is procedural planning, in Faludi’sbelief, that can improve planning theory. Procedural and substantive theories, however, as some scholars and practitioners argued, cannot be studied separately because planning process cannot be done without an understanding of its substances (Stiftel, 2000).

While rational planning approach has remained “orthodox” in practice over the decades, it has gained new implications by integrating with other disciplines, such as system analysis, operational research, and philosophy. One example that could be particularly valuable for complex planning issues, such as waste management, is the plan justification process proposed by Faludi (1986). He referred to Popper’s falsification theory (1961), which indicates that we can only obtain truth by falsifying hypotheses instead of verifying them by generalize them. Rather than rejecting falsification process, Faludi argues that planners may approximate truth by falsifying hypothesis, which can be a rational planning process and involves learning (p. 50). In the case of waste management, current practice (such as landfill disposal) is generally believed to be the lowest cost solution. If additional information and knowledge provide a basis to demonstrate it is not true, then a diversion from landfills can be justified. Although an alternative plan may not be the best solution, this “critical rationality” thinking helps planners approximate the truth.

Reflecting on the historical development in planning theory over two centuries, Friedmann (1987) categorized four major traditions of planning thoughts: social reform, policy analysis, social learning, and social mobilization. Each of these traditions apparently can play a role in waste management and planning, such as advances in waste management science and technologies, enhanced economic analysis, “learning by doing” process, and bottom-up participation of environmentally educated people.

More recently, new approaches have emerged to address the vast uncertainties and limited knowledge of environmental systems, such as adaptive management and collaborative decision-making, which pay particular attention to the dynamics of environmental planning and the values of communities (Healey and Shaw, 1994; Randolph, 2004; Haughton and Counsell, 2004). In particular, Norton (2005) argues for three key tenets for adaptive management: experimentalism (given the uncertainties), multiscalar analysis (of space and time), and place sensitivity (i.e., every management challenge is unique and may be an opportunity for new ideas and techniques). It is the "forward-looking" perspective of adaptive management that makes Norton believe that adaptive management is crucial for sustainability (pp. 110-153). Waste management provides rich examples of the challenges and need of each tenet for adaptive management, and consequently, sustainable development, as the following chapters will elaborate on.

URBAN SYSTEM THEORIES

Intensive human activities in cities often require imports of resources and transform raw materials, energy, water into the built environment, air emissions, and waste. As early as 19th century, Marsh looked into the historical degradation of nature along with human development and asserted that humans had played a destructive role in the nature transformation. He contended that humans should respect the laws of nature and act as coworkers of the nature, because man and nature shape each other (Marsh, 1864).

Wolman's (1969) analogy of city activities as a metabolism process represents pioneering research on system-wide impacts on resource consumption and waste generation in an urban environment (Decker et al., 2000).Wolman argued that "the metabolic cycle is not completed until the wastes and residues of daily life have been removed and disposed of with a minimum of nuisance and hazard" (p.276). Wolman further demonstrated the problem in the case of water use in a hypothetical city in the U.S. With a particular focus on waste materials, Bower (1977) introduced the concept of “residuals” and the model of residuals-environmental quality management (REQM), and the criteria to evaluate REQM strategies.

Since the first study by Wolman half a century ago, at least 20 comprehensive studies have been undertaken across the world (Kennedy, Pincetl, and Bunje, 2010). It is noteworthy that a majority of the current case studies are located in European or Asian regions. It appears only two studies were conducted in the U.S.; one by Zucchetto (1975) in Miami, and the other by Ngo and Pataki (2008) in the Los Angeles County. Researchers have found that material flow analysis, especially at a refined geographical scale, is rather constrained by data availability than by methodology (Leigh et al., 2007b).

Data requirements are particularly a challenge for urban system analysis also because a uniform unit of measurement is typically needed. Three common types of measurements have been adopted by researchers in urban system models: (1) material masses (such as Niza, Rosado, and Ferrão, 2009); (2) energy (such as Odum, 1983); and (3) land area, which is associated with studies of carrying capacity and ecological footprint. Carrying capacity refers to “the level of population or development that can be sustained in an area without adversely affecting that area beyond an acceptable level” (Randolph, 2004, p.604). Even if technology innovations may increase the carrying capacity, researchers represented by Meadows argued that the current pace of population growth, industrialization, pollution, resource depletion may create the limits of growth on this planet in an abrupt way (Meadows et al., 1972, 1992). Ecological footprint measures the amount of biologically productive land area needed to sustain resource consumption and to assimilate residuals from a person, a region, or an activity, such as manufacturing a computer (Wackernagel and Rees, 1996). Embedded in life-cycle thinking, ecological footprint analysis can be used as an indicator for self-sufficiency and sustainability in an easily comprehensible way.

Both theoretical and empirical studies on urban systems suggest that urban and environmental systems are interdependent and thus we must consider environmental processes as drivers of urban change (Alberti, 1999). Urban systems cannot be sustainable if it requires more resources than it can produce and generates more waste than it can assimilate.

The integration of urban system models and economic system analysis, although not always recorded in the same unit of measurement, represents a significant advancement in system analysis in that previously separated systems are finally considered as one unity. Based on the regional economic input-output model that was developed by Leontief in 1936 to trace the flows of goods and services among sectors, Leontief and Ford (1972) extended the economic input-output model that originally developed to examine air pollution problems. Pattern (1976) and Finn (1977) extended the framework of economic system to ecological systems. Applications of environmental input-output framework have proliferated after these pioneering studies (c.f., Thoss and Wiik, 1974; Hendricks, 1982; Xie et al, 1991; Bouhia, 1998; Chen, 1990, 1992, 2000). These studies have covered both marketable environmental goods (e.g., water supply for production and consumption) and non-market environmental goods (e.g., water inventory – rivers, lakes, etc.). The section below further discusses the reasons and methodology of integrating environmental goods into economic system analysis, with special considerations about the externalities of solid waste.

EXTERNALITIES AS A SOURCE OF MARKET FAILURE

Externalities exist when the activities of an agent, such as a firm or a household, generate impacts on others' welfare but the agent does not bear all of the consequences (Tietenberg, 2000). Externalities can be either positive or negative, although the negative ones that are of major concern to the public interest. If there were no market externalities, all the agents would determine such level of production and consumption that is the most efficient in the perfectly competitive market based on rational considerations for profit. However, externalities are not uncommon. Some examples may include air pollution from manufacturing process, noise nuisance from parties, aesthetics value to the neighborhood with well-groomed lawns.

While waste disposal facilities typically generate negative externalities, their impacts are not adequately reflected in the current pricing system. Frequently, urban waste collection services are subsided by the tax revenue, which makes waste generators deem they deserve the right to discard, regardless of the volume. Moreover, the common practice of the flat-rate fee system for waste collection and disposal does not provide any profits for waste generators to reduce waste reduction (Jenkins, 2003).

For private waste management firms, their for-profit decisions of the efficient level of recycling are made when the marginal cost of recycling equals to the marginal cost of disposal. Because indirect and social costs are not included the in waste disposal fees, the marginal private cost of waste disposal is less than the marginal social cost of disposal. Thus, the efficient level of recycling that private firms determine (Q_1) would be lower than the level optimal for the public (Q_0), as illustrated in Figure 3.2. Incorporating the economies of scales as experienced by the waste management activities, Figure 3.2 is only a rough representation of the private and public cost structure and attempts to illustrate why private sector tends to recycle less than the optimal level if the negative externalities of waste disposal are not internalized in the disposal fees.

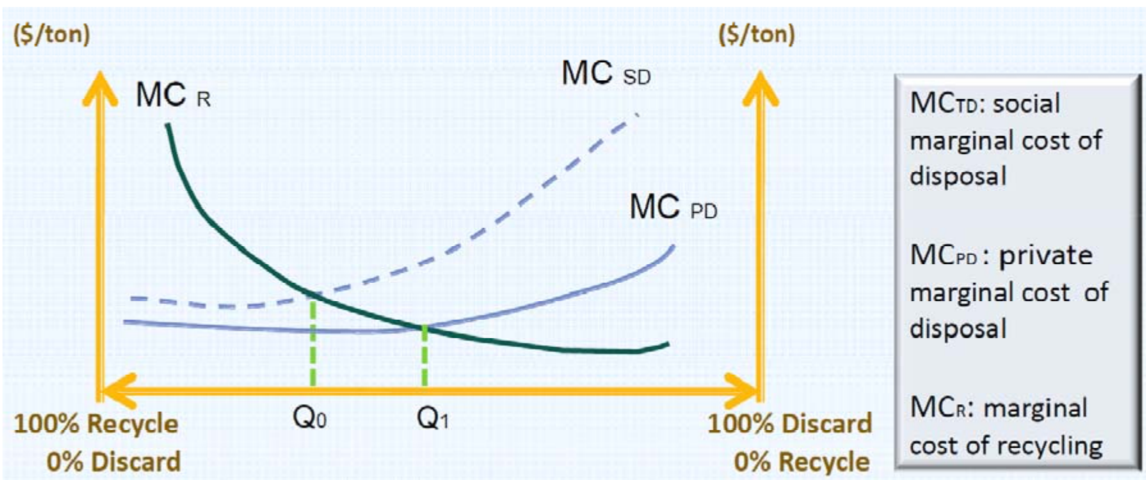

Figure 3.2: Efficient Level of Recycling

Note: Figure is adapted from Tietenberg T. H. (2000). *Environmental and Natural Resource Economics*. Boston, MA: Addison Wesley Longman. p.191.

To internalize negative externalities of waste disposal into waste material pricing, policy makers need to ascribe a monetary value. Up to date, approximately a dozen of techniques have been developed to monetize environmental goods (Tietenberg, 2000; NOEP, 2008). Eight techniques that can be applicable in evaluating the externalities of waste management are summarized here:

- Avoid Cost Method – uses the cost spent in pollution prevention as a proxy for environmental resources (such as clean water and clean air).

- Contingent Valuation Method (CVM) – usually uses surveys/questionnaires for people's willingness to pay (WTP) or willingness to accept (WTA) to elicit values for environmental goods and services upon hypothetical situations. Up to date, researchers generally agree that CVM is the only method that can be applicable to evaluate the non-use value of environmental goods.
- Hedonic Pricing Method – estimates economic values for ecosystems or environmental services that directly affect market prices. The advantage of this method lies in its design to control certain variables when evaluating environmental goods. It is commonly used to evaluate impacts on housing price, such as the impacts of landfill facilities on the adjacent property value.
- Travel Cost Method –mainly used to evaluate the value of a recreational site (such as an open space). The information of visitors' willingness-to-pay (WTP) to visit the site is used to construct a travel-cost demand function of the site.
- Discrete Choice Method – asks people's preference over a combination of factors in discrete values (integer or ordinal value). For example, people may choose to trade-off the travel distance and the scenic quality along a travel route. Then the researcher quantify the trade-offs between attributes. Potentially, this relationship can be translated into economic values (such as the value of travel time and fuel cost).
- Market-Value Method–evaluates the changes in environmental conditions by determining the market value of changes in productivity. For example, analysts can estimate the impacts of water pollution by calculating the losses in fishery production, or the impacts of soil degradation by calculating the changes in the

yield of certain crops grown on those lands affected. To transform these impacts into a monetary value, analysts can multiply the losses in productivity by the market value of the crops.

- Human-Capital Method–evaluates the economic loss caused by health impacts on those working people exposed to environmental pollution. It adopts an opportunity-cost approach and estimates the foregone property, resources, and human lives by the maximum value they could have produced (e.g., income). Since people at different stakes may claim different lost value, the method may involve a large range of estimation results.
- Benefit Transfer Method – when data, skill, and costs become a major constraint for a researcher to collect data and analyze on his/her own, researchers resort to previous studies on similar cases and make necessary assumptions/adjustments to estimate the study region.

In many cases, environmental and economic evaluation techniques need to be connected with other approaches. For instance, human capital method can be integrated with dose-response analysis to evaluate the economic impacts of air pollution in Beijing (Ai and Polenske, 2007). In a dose response analysis, scientists derive the quantitative relationship between the amount of exposure to a substance and ensuing toxic injury or disease from regression analysis of sample statistics, and subsequently, employ the derived relationship to estimate possible impacts of pollutants on human health (SRA, 2011). When connecting human capital method and dose response analysis, air pollution impacts on public health can be estimated in economic terms. This will further allow regional I-O, SAM, and CGE modeling, and an integration urban system models and economic system analysis discussed earlier.

Note that each technique may have limitations, thus may not be ideal for all types of environmental problems. In addition, each technique may involve analysts' subjective judgment, and possible biases. For example, Tietenberg (2000) argues that contingent valuation method may incorporate four types of potential biases (1) strategic bias, (2) information bias, (3) starting point bias, and (4) hypothetical bias (p. 39).

In another example of Hedonic-Property Method (HPM), analysts collect data on housing sales prices and housing characteristics to estimate the demand function, and then estimate the value of local environmental amenities when controlling other factors to be the same. The difficulty is that analysts need to confirm that the real-estate markets to be examined are active and healthy. Furthermore, it is hard to separate other factors that may influence the housing prices from local environmental amenities.

The techniques and potential biases in the economic evaluation of externalities determine that estimations of externalities are more accurate in region- and context-specific analysis. To address such limitations, a sensitivity analysis is particularly helpful.

REGIONAL ECONOMIC GROWTH VS DEVELOPMENT

Solely from an economic perspective, the waste industry apparently shares many similar characteristics with other economic sectors. These similarities provide researchers an opportunity to seek policy insights from regional economic theories, as discussed below.

While there is no single definition for regional economic growth and development, the objectives usually include increases in tax revenues, jobs, and income. Towards these objectives and sometimes beyond, researchers adopt different approaches (e.g., descriptive analysis, empirical analysis, and mathematical modeling) and focus on different perspectives (e.g., drivers for regional convergence and divergence, endogenous and exogenous factors, distinction between growth and development, and evolutionary and institutional aspects).

This discussion focuses on four theories that are most pertinent to the waste industry: (1) export-led growth theories, (2) location and trade theories, (3) new economic geography, and (4) agglomeration and industrial clusters. As Hoover and Giarratani (1999) indicated, no single factor results in economic growth alone, given the complex interactions among socioeconomic activities in a region. Therefore, a review of the theories by no means suggests one best choice. Instead, this section aims to present various approaches to promote a region's economy in relation to the waste industry. This section makes a distinction between "growth" and "development" at the end of the theory review and follows with a discussion on why such differences may have a significant impact on waste management policy-making.

Export-Led Growth Theories

Export-led growth theories maintain that exporting activities are the driving force of a region's growth. The most influential of these theories is economic base theory. It divides industries into two categories: basic and non-basic. The "basic" industries produce goods and services for export, and further, generate multiplier effects on the local economy through inter-sectorial linkages. The basic industries may also stimulate “non-basic” industries that produce for the local market. Thus, economic base theory emphasizes the basic industries for regional wealth and job creation (Tiebout, 1956).

Economic base theory presents great simplicity to explain regional growth and has been widely adopted as a rationale for business recruitment programs. However, the model is criticized for its short-term horizon, since export activities are driven by external demand, which is dynamic in nature. The model also tends to overstate the importance of exports and ignores the characteristics of local production factors (Tiebout, 1975; Malizia and Feser, 1999).

As an extension of economic base theory, staple theory incorporates a long-term perspective. The “staple” commodities refer to those raw materials that can be processed locally with a comparative advantage in the world. The production of the staple commodities thus becomes the export base and evolves across time (Innis, 1933; Watkins, 1963).

Although export-led growth theories appear to be the simplest and the most popular method of explaining regional growth, critiques correctly point out that exports would not be the single or major factor of regional growth; otherwise the global economy would not have developed if the globe was considered as a closed system (Tiebout, 1956). In addition, if a region solely relies on exporting activities, it can be vulnerable to economic fluctuations due to dynamic demand outside the region.

Location and Trade Theories

Location and trade theories seek to explain how firms make location decisions and develop those decisions to incorporate local characteristics. In essence, location and trade theories hypothesize that local economic factors (e.g., capital, labor, energy, and the market) and resource endowment (e.g., land, raw material, and transportation access) result in comparative cost differentials and consequently enable trade across regions (Weber, 1929; Hoover, 1937; Isard et al., 1998). The scarcity of production factors in relation to demand both within and outside the region determines the price discrepancy (Heckscher, 1919; Ohlin, 1933; Samuelson, 1953). Location decisions are made to minimize the total cost of production and transportation. Classical location and trade theories, however, cannot explain trade activities in regions with similar production factor attributes (Dicken, 1998).

New Economic Geography

New economic geography, pioneered mainly by Fujita (1988), Krugman (1980; 1991), and Venables (1996), has relaxed some of the rigid assumptions in classical location and trade theories when explaining industry location decisions. It allows the assumptions of imperfect competition and increasing returns, and formalizes the assumptions in quantitative models. It regards production factors as mobile, and thus focuses on the interaction between transportation costs and economies of scale in production. For regional economies to grow, regions should strategically promote the industries that may generate economies of scale, both in production and in transport (Krugman, 1980 & 1991).

Agglomeration and Industrial Clusters

This set of theories stresses the spatial proximity of industries and connects industry-level decisions with regional-level impacts. When a number of industries are located in proximity, two factors play a central role in promoting regional economic development: scale economies and competitiveness.

Discussions on scale economies can be traced back at least to the 1890 publication of *Principles of Economics* by Alfred Marshall (Bekele, 2009), who demonstrates the external economies of scale generated from the concentration of specialized workers and economic activities. Further, Ohlin (1933) and Hoover (1937) differentiate *localization economies* from *urbanization economies*. The former arises when firms in the same industry cluster and share market information as well as specialized production inputs. The latter arises when different industries cluster, leading to cost savings in transportation, advertising, and more.

Porter (1990) more explicitly connects the spatial concentration of firms with regional economic development. According to Porter, a region's prosperity depends on the competitiveness of the industries that comprise industry clusters. The cluster, by his definition, includes not only buyers and suppliers of inputs, but also the providers of service and infrastructure that can support technical advances, research, and education (Porter, 1990; Bekele, 2009). In Porter's cluster theory, innovation capacity is the fundamental factor to promote economic growth and to advance a region's competitiveness.

The theories reviewed above emphasize that economies of scale are a key factor for the growth of regional economies. More recent theories have put more emphasis on the role of knowledge and innovation, and on the dynamics of space and time. Such a theoretical trend is consistent with the practical need of differentiating *growth* from *development*, as is elaborated upon below.

Growth vs. Development Theories

Although the difference in the concepts of growth and development was under discussion decades ago (see Flammang, 1979), classical regional models in general did not make a clear distinction between "growth" and "development." The distinction became a heated and popular issue in the 1990s, mostly due to environmental and social concerns. The most influential publications are "Our Common Future" by the World Commission on Environment and Development (WCED) in 1987 and the Rio Declaration on Environment and Development at the United Nations Rio Earth Summit in 1992 (WCED, 1987; UN, 1992). These reports raised worldwide concern for environmental pollution and social inequity, which have been generated by intensified economic production as well as excessive consumption. More notably, the WCED proposed the notion of "sustainable development". Sustainable development aims to meet the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987), which highlights the "3E" principle that balances the values of the Environment, Equity, and the Economy.

Since then, economic development theories have put more emphasis on the quality of life, the role of technology and innovation, and environmentally friendly production. Fitzgerald and Leigh (2002) identified five sequential but also overlapping stages of economic development: business recruitment, land development in the interests of a few elites, pursuit of social equity, integration of sustainability, and privatization and interdependence. In other words, economic development may not be simply an extension of economic growth; it opposes environmentally and socially undesirable production activities that are traditionally regarded as growth.

To distinction this broader concept from traditional growth, researchers have also termed "sustainable economic development." Blakely and Leigh (2010) argued for three essential elements of sustainable local economic development: (1) increasing living standard for all over time; (2) reducing economic, social, and spatial inequity; and (3) promoting sustainable material use and production (p.75). In the past decade, there have been growing discussions on the local strategies to promote sustainable economic development. Some examples include brownfield remediation and redevelopment, eco-industrial park and green manufacturing within urban regions, "Green Building Initiatives", and strategic material flow management (Fitzgerald and Leigh, 2002; Portney, 2003; Allen and Potiowsky, 2008; Leigh, Ai, and French, 2010; Grodach, 2011). In the case of waste management, while economies of scale in production may promote growth, they are not sufficient for sustained growth and may have opposite effects on regional sustainable development.

POLICY IMPLICATIONS FOR WASTE MANAGEMENT

With a special focus on landfill services, this section discusses the policy implications for future waste management. It first regards the waste industry solely as a traditional economic sector and examines whether or not a pro-landfilling policy can be an economic strategy to promote a regional economy. Then, it incorporates the consideration of environmental and social impacts of landfilling activities, and discusses the implications for public policy on waste management.

Landfills as a Traditional Service Sector

When treating waste management solely as an economic service sector, a region would aim to increase the competitiveness of the sector and decrease production costs. Thus, the fundamental and critical question is whether a region should increase exports or find import substitutions. In particular for waste disposal services, there are two development paths: (1) To increase exports (of waste management services), the sector needs to expand its production capacity (i.e., host new landfills or expand existing landfills); and (2) To decrease service imports from other regions, the sector needs to increase efficiency and find import substitutions.

From a theoretical perspective, the first approach of the pro-landfilling strategy may lead to regional growth. Indeed, it has external demand, presents economies of scale, and can achieve cost advantages of production owing to local conditions (i.e., land cost) as well as large-scale production. According to classical regional theories, all of these characteristics may promote a region's economy. To elaborate, when a region expands its waste disposal capacity, it may achieve both internal and external economies of scale. Given the cost reduction in waste disposal, the production cost in other industries located in the region may decrease as well, which could be an attractive factor for other waste-generating industries. In addition, the region could accept more waste generated in other regions, and thus receive more revenue. All scale economies can be tangible in the short term, especially when a region has ample capacity in existing facilities and does not need new construction. In terms of job opportunities, however, the pro-landfilling activities could be minimal.

In contrast, the second approach, seeking import substitutions, appears to require more efforts. The region would need to increase the efficiency of waste disposal (e.g., waste compacting, landfill gas to energy), and meanwhile, achieve waste reduction and diversion. A series of programs are necessary, including public education to increase the recycling participation rate, research and development in material recovery and reuse, and market development to promote recovered materials. Although economic theories consider technology and innovation as the fundamental force of regional competitiveness, the implementation requires considerable resources and time. When solely considering landfill services as an economic sector, the pro-landfilling strategy has an apparent advantage in the short run. Indeed, this explains the reality that landfill disposal services are more appealing than recycling programs in some regions.

Landfills as an Industry with Undesirable Externalities

While traditional economic theory would support pro-landfilling programs from a growth-led production perspective, the negative externalities of landfill disposal activities (e.g., environmental pollution, health impacts, and depreciation of property value) may incur costs that are not readily apparent or immediately measurable.

For example, that external costs of landfill disposal are not currently internalized into its pricing system leads to distorted market prices for waste disposal and other waste management methods. With decreasing costs due to economies of scale, landfill facilities generally provide discounts for large volumes of waste "supply" and may also set increasing disposal rates for small loads. To achieve greater economies of scale, landfill facilities also have an incentive to reduce tipping fees to attract more incoming waste, as executed by Salt Lake City, Utah (Richards, 2006). It is critically important to acknowledge the competitive relationship between waste management methods, when they together manage a region's waste. Without corrected market prices for waste disposal, current policies only deter the efforts of waste reduction, although they are the most preferable option of waste management suggested by the U.S. EPA.

From a macro perspective, the present indicators of economic growth, such as Gross Regional Product, cannot accurately reflect the cost of waste disposal to a region. Moreover, they potentially encourage excessive consumption of materials and product. As Daly (2001) argues, the costs of pollution cleanup and discovering new resources increase along with economic growth. When the marginal cost of production reaches the level of the marginal benefit, economic production will no longer lead to growth. In practice, the expenses of waste disposal services to a region only count towards a higher economic output in the sector. In addition, traditional regional economic accounts do not reflect the opportunity costs of landfilling when the embedded value of materials and energy recovered from recycling is permanently lost.

Continuing the practice of pro-landfilling activities may also lead to widening environmental and socio-economic disparities. As revealed from agglomeration theories, low-cost waste disposal services can be an appealing factor to attract other waste-generating industries. This suggests a pro-landfilling region would be more likely to be a cluster of polluting industries, rather than of industries with higher pay and higher technology components. Since some environmental impacts can be irreversible, the cost of pollution control and remediation can be prohibitive in the long run. In other words, regions that host polluting industries may experience particularly harsh difficulties when facing regional competition along the development path.. In addition, as long as differences in landfill tipping fees can justify the transport costs, waste-generating regions can export waste to a remotely distant destination with low tipping fees, which is commonly associated with cheap land cost, lagged economic development, and weak capacity of social advocacy. Consequently, the claimed benefits of landfills, even if taking place, would only contribute to "economic growth" in the distressed regions in the short term, instead of promoting the principles of economic development; namely, equity, quality and sustainability.

Summary

The opposite conclusions above reveal the limitations of traditional economic growth theory when examining an industry with undesirable externalities. They also help explain why landfill proposals are welcomed in some regions, and demonstrate the potential problems if the present paradigm of waste management continues. From the perspective of narrowly defined "economic growth," land disposal services can bring tax revenue to a region in the short term. However, the short-term growth is at the sacrifice of long-term development, such as competitiveness, social equity, and environmental capacity. Thus, pro-landfilling activities cannot promote sustainable development, or even sustained growth. The following chapters extend theoretical discussions with empirical analyses.

CHAPTER 4

IMPACTS OF URBAN GROWTH ON WASTE GENERATION AND RECYCLING

This chapter explores empirical data and examines whether urban growth canbe decoupled from waste generation increase. If yes, this chapter investigates what factors may have promoted waste reduction. This chapter begins with a literature review, followed by a discussion of the design, hypotheses, and strategies of data collection and processing for this research. The concluding section discusses the results of the panel data analysis, policy implications, as well as limitations of this research.

LITERATURE REVIEW: WASTE GENERATION MODELING

Unlike other centralized urban services, such as water and electricity that can be traced for each end user waste generation volume is more difficult to measure at the source. Waste disposal/recycle volume data are typically collected at waste management facilities, by weighing the trucks entering the facilities. An aggregate tonnage from all waste management facilities is considered as the total disposal volume of waste managed in the region. This metric, however, does not always record the "origin" of the waste. Thus, the total volume of waste disposal that is collected by all the facilities located in the county may not reflect the accurate volume generated by the county. Most regions both import and export wastes but do not require the tracking of MSW exports, although it is more common to record the imports of out-of-state wastes.

At the U.S. national level, there are two major sources of waste statistics: one is the U.S. EPA's annual report "Municipal Solid Waste Facts and Figures" conducted by

Franklin Associates, and the other is the "State of Garbage in America" (SOG) reports. The latter are annually published by Biocycle, which has prepared surveys of state waste management agencies every year since 1989 (except 2003). There are considerable differences between the data published by Biocycle and the U.S. EPA (Appendix Table A.1). Data at the state and local levels are updated less frequently and involve more uncertainties.

The data gap and uncertain quality of data have led to many studies modeling waste generation that can date back to the early 1970s. The research can be generally categorized in two groups, in terms of research purposes: (1) identifying factors that have contributed to waste generation (i.e., casual models); and/or (2) projecting waste generation using presumably explanatory variables (i.e., predictive models).

In addition to modeling purposes, the previous studies have differed in:

1) Scope of analysis: MSW as a whole, residential waste only, or material specific;
2) Unit of analysis: country, state, city, district, and household;
3) Data frequency: yearly, monthly, daily, and even hourly;
4) Modeling methods: simplicity vs. sophistication;
5) Data reference: questionnaire surveys, field data collection, regional waste reports, market-research studies, or hypothetical;
6) Exploratory variables: household, socio-economic, commercial, institutional, etc.

The subsections below elaborate more on the modeling methods and exploratory models.

Waste Generation Estimation Methods

Waste generation modeling can be generalized into the following five approaches. First, and the simplest approach, is to regard uniform characteristics across regions and use the per capita national average. An improved per-capita approach involves category models, or stratified analysis, by household income or economic sectors.

The second approach is trend analysis. A region refers to its own one-time or periodical surveys/sample sorting results and project into future. Trend analysis can use either a linear, exponential, or s-curve model, based on historical data (Bridgewater, 1986; M.E.L., 1986).

The third approach is material flow analysis (MFA), which relies heavily on industry and trade statistics. The fourth approach is economic input-output models (I-O), which differentiate industry sectors and examine the inter-sectorial material flows. Any implementation of MFA or I-O models below the national or state level, however, is greatly hindered by data constraints.

The fifth approach is computational modeling, such as the saturation curve method and least-squares regression method. These methods, however, are not common for waste forecasting analysis in the U.S. because researchers are concerned about the "limited samples in the real world systems" (Chen and Chang, 2000). Accordingly, researchers have developed fuzzy goal regressions, grey dynamic models, and integrated models that have evolved to incorporate uncertainties in waste generation modeling with the assistance of advanced computerized models (Chen and Chang, 2000; Dyson and Chang, 2005). Given the various choices of waste generation modeling and the limiations of waste statistics, researchers acknowledge there needs to be a compromise between "information gain and cost-efficient model development" (Beigl et al., 2008).

Exploratory Variables

Either quantitatively or descriptively, researchers have studied five general categories of factors related to MSW generation: economic, demographic, housing structure, geographic, and policy. A summary table of variables examined by the previous studies is presented in Table 4.1, which is largely based on two existing review articles – Beigl et al. (2008) and Mazzanti et al. (2008).

Demographic and socioeconomic factors are most common in waste generation modeling, mostly because data are widely accessible. Some studies expand the scope of explanatory variables to include waste management policy, but are limited to case studies of a small sample size. While most studies focus on residential wastes, a few have incorporated commercial and institutional factors (Hockett, Lober, and Pilgrim, 1995).

Identifying exploratory variables that are universally consistent among the existing studies can be difficult. Previous studies reached mixed results for many variables in Table 4.1. Technically, each study has examined tempo/spatial data in a specific community. Local characteristics and inconsistencies in measuring metrics apparently threaten the external validity of the results. In addition, some explanatory variables may play two-sided roles. For example, while researchers generally agree that economic status is positively correlated with waste generation, some also argue that affluence can be associated with higher participation rates of household recycling and better systems to manage waste with advanced technology (e.g., Saltzman et al. 1993; Schultz et al., 1995)

Table 4.1: Exploratory Variables of Waste Generation: Literature from 1970s to 2000s

Category	Variable	Example References
Economic	Income/Affluence	Rhyner, 1976; Wertz, 1976; Richardson and Havlicek, 1978; Chang et al., 1993; Dayal et al., 1993; Ali Khan and Burney, 1989; Grossman, 1974; Rathje and Murphy, 1992
	Retail Sales/Private Consumption Expenditures	OECD, 2004; Christiansen and Fischer, 1999; Daskalopoulos et al., 1998; Hockett et al., 1995; Gay et al ,1993
	Value Added by Manufacturing	Hockett et al., 1995
	Construction Costs	Hockett et al., 1995
	Employment	Dennison et al., 1996a; Bach et al., 2004
	Industry Structure	Bach et al., 2004; Hockett et al., 1995; Gay et al., 1993; N.C. Department of Environment, Health, and Natural Resources, 1992
	Tourism	N.C. Dept of Environment, Health, and Natural Resources, 1992
Demographic	Age	Jenkins, 1993; Beigl et al., 2004; Richardson and Havlicek, 1978
	Household Size	Dennison et al., 1996b; Jenkins, 1993; Cailas et al., 1993; Rhyner, 1976; Richardson and Havlicek, 1978
	Education	Hong et al., 1993
	Race	Hong et al., 1993
	Life Expectancy/Infant Mortality	Bogner et al., 1993; Beigl et al., 2004, 2005
	Household/Family Life Cycle	Parfitt et al., 1994
	Consumption habits	Dennison et al., 1996a
Housing Characteristics	Tenure of Property	Dennison et al., 1996a
	Rental Rate of Poverty	Abu Qdais et al., 1997; Grossman et al., 1974
	Dwelling Type (SF vs. MF)	Emery et al., 2003; Parfitt and Flowerdew, 1997; Dennison et al., 1996a
Geographic Characteristics	Population Density	Cailas et al., 1993; Jenkins, 1993; Eder, 1983; Hockett et al., 1995; Khan and Burney, 1989
	Degree of Urbanization (% of Urban Population)	Hockett et al., 1995; Cailas et al., 1993; Henricks, 1994; Rhyner, 1976
	Climate	Dayal et al. 1993, Jenkins, 1993; Ali Khan and Burney, 1989
	Heating Method	Dennison et al., 1996a
Waste Management Policy	User Fees	Jenkins, 1993; Hockett et al., 1995
	Waste Disposal Fees (Tipping Fees)	Hockett et al. 1995
	Container Type (e.g., size, whether with wheels)	Coggins et al. 1992; M.E.L. 1993
	Density of Collection Sites	Bach et al., 2004; Parfitt et al., 2001
	Frequency of Garbage Collection	Tchobanoglous et al., 1993

Note: Table 4.1 is created largely based on Beigl et al. (2008), Mazzanti et al. (2008).

Summary of Literature and Research Gap

Although researchers have undertaken rigorous efforts for waste generation modeling, the geographic scope of the studies has been limited. The region-specific studies have yielded mixed results. On the one hand, they may confirm the need for region-specific policy design. On the other hand, the existing studies do not provide external validity for regions without waste generation studies.

Notably, many more studies have conducted in the European regions than in the U.S. This could suggest that the European countries pay more attention to waste management issues, and accordingly, have undertaken more efforts in waste volume tracking and recording. In addition, most studies are conducted on the basis of single period data. Panel data analyses are limited, thus the findings from previous analysis in certain regions may not be valid to the other regions.

RESEARCH DESIGN

This study endeavored to develop a cross-year and cross-jurisdiction analysis at the county level, at which municipal solid waste is managed and waste stastistics are commonly collected. There are two study periods: 2000 and2005. This panel data analysis did not track back to periods earlier than the year of 2000, because waste statistics often present inconsistencies over the years and cannot support a longer time-span of study with a reasonable size of observations for regression analysis. The selection of the year 2000 as the base year allowed this study to have a much larger number of observations and thus facilitated the panel data analysis. Because waste statistics are reported with a certain period of delay, the contrast year was chosen for 2005, when waste data were available online at the time of this research.

Given the presence of inter-regional waste flows, this study paid particular attention to the disctinction of waste volume "by origin" versus "by destination."A county's waste disposal volume "by origin" is the volume of waste disposed within the county, plus the volume exported to other counties, and minus the volume imported from other counties. In contrast, a county's waste disposal volume "by destination" represents the volume of waste that is accepted at the disposal facilities within the county, regardless of its origin. Waste volume "by origin" was selected as the indicator of this study, because it reflects the source of the waste generation and provides references for long-term waste management planning as well as waste-reduction policy design.

The numerial study started with a correlation analysis to test whether a county's waste generation volume can be decoupled from its urban growth, specifically, population growth. Next, a regression analysis was conducted to examine the causal factors. Given the two causal factors of waste volume: (1) population size and (2) per capita waste volume. If the scale of population growth outweighs the reduction of per capita rate, the total waste generation volume will still experience an increase. However, if a region aims to achieve waste reduction given its population growth, the per capita waste generation rate has to be reduced. Therefore, the dependent variable of this study was in per capita terms.

In particular, this study included three dependent variables of interest: (1) per capita waste generation volume; (2) per capita waste disposal volume; and (3) per capita waste recycling volume. The recycling rate (sometimes interchangeable with "diversion rate", which sums up recycling and composting as being "diverted") has become the single and major indicator to measure the success of the waste management practice at local level. While individual communities may adopt somewhat different methods and units to document waste management data, in practice, waste volume is mostly recorded as the weight of waste materials (in tons). This was the measurement used in this study as well.

As discussed in Chapter 2, the volume of waste disposal and the volume of recycling complement each other. A person with a higher waste generation rate may not send more waste for final disposal in landfills, if the person actively recycles. Thus, to reduce waste disposal volume requires a systematic examination of all three indicators: generation, disposal, and recycling.

The independent variables were selected through several iterative processes, on the basis of (1) literature review, (2) data availability, and (3) detected relationships among variables of interests. Instead of an exclusive list of independent variables, this study favored a small number of variables for several reasons. First, waste statistics are only available in a limited number of jurisdictions, which determines that fewer variables may create a larger degree of freedom for regression analysis than more variables in this case. Second, several variables of interest (such as population and employment) may have high correlations between each other, which presents multicollinearity and creates threats to the validity of regression analysis. A representative set of independent variables may result in more accurate testing results than a long but correlated set. Thus, this study only focused on a few representative variables in the following three categories:

a. Demographic: income, age, race, and employment
b. Urban form: population density, the percentage of single family housing, travel time to work, and building age

c. Waste management policy: whether a waste service, such as Pay-As-You-Throw (PAYT) policy, is implemented.

Several other policy indicators may also play a role in waste management performance, such as the availability of waste management facilities within the county, regional average tipping fees, household garbage fees, and implementation of curbside recycling. After a careful literature review, this study determined that data constraints would prevent from including all these variables in a national-level analysis. In the case of waste management facilities, the number of landfills is often easy to locate in publicly accessible databases. However, landfills vary greatly in size; their regional impact is determined by both number and capacity (measured either in tons or usable years). Per capita landfill capacity information would be a better variable for policy analysis. But the capacity estimates are not always readily available, partially because it can be highly dynamic, given both technology advances and policy updates. Meanwhile, the availability of waste management infrastructure can be essentially translated into economic terms, such as landfill tipping fees and household garbage fees, which may have direct impacts on waste generation rates. Data about such economic instruments are extremely limited, largely because the increasing privatization of waste management service, in terms of both waste collection and disposal. When municipal services are contracted to private sectors, communities receive various levels of services from different companies, and the fee structure varies too. Such variations are not commonly published. Thus, it has become difficult to calculate a county or regional average without knowing the full picture. This is the same case with curbside recycling programs.

Theoretically, the availability of curbside recycling programs facilitates households' recycling, and thus may be associated with a decrease in waste disposal volume. Such hypothesis is hard to demonstrate in this nation-wide and county-level analysis, because curbside recycling programs frequently are only provided partially to county residents. The percentage of households served is hard to determine in most cases. Case studies with a focus on one or few communities may be feasible when data allow. To include multiple policy variables seems to necessitate a refined geographic level of analysis than a county, which was beyond the scope of this study.

Acknowledging that the selected is by no means an exclusive list of exploratory variables, this study adopted fixed effects models for the panel data analysis. One-way fixed effects models are designed to capture unobserved heterogeneous effects that remain fixed (constant) for the same county over years (such as climate and consumption patterns), or those effects that remain constant in the same year for different counties (such as economic condition). To capture both of these effects, two-way fixed effects models need to be adopted. This study conducted both one-way and two-way fixed effects models for all three regressions, and performed F-tests to determine which model was valid if two models revealed different results. The following sections elaborate on the data collection and processing strategies, the descriptive statistics of the variables of interest, and the steps of panel data analysis given the chacteristics of the data sets.

The major goal of this study was to identify the factors that have the potential to promote waste reduction and that waste management planners should focus on. It was not intended to enhance the accuracy of predictive model, because waste generation volume can be influenced by many unpredictable changes, such asproduct consumption, technology, and public behavior. Assuming a business-as-usual scenario, however, this study could provide reference for waste generation projection in the future.

DATA COLLECTION AND PROCESSING

The panel data collection process started with a county selection process, which included the following steps. First, a list of 3,141 counties or county equivalents ("counties" thereafter) was gathered from the U.S. Census. Second, 1,100 counties or county equivalents that are located in metropolitan areas were identified, again, through the U.S. Census. Third, the population growth rates between 2000 and 2005 for each metropolitan county was calculated on the basis of the Census data and compared to the national average (5.3%). A total of 500 metropolitan counties that experienced higher population growth rate than the national average were selected for the next step of study. Fourth, this study narrowed the selection to 100 counties that had 250,000 residents or more in 2000 and were covered in the American Community Surveys (ACS) and ACS Supplement Surveys, which provide most of the demographic data for independent variables of this study. Finally, after going through each of the 100 fast-growing populated counties, this study confirmed 39 counties that provided the necessary statistics of waste management for the purpose of this study. The county selection process is summarized in Table 4.2. Spatially, the selected counties are distributed in five of the nine census divisions: the Pacific, West North Central, East North Central, South Atlantic, and Middle Atlantic (Figure 4.1).

Table 4.2: County Selection Process

Selection Criteria	Number of Qualified Counties				
Counties or county equivalents	*	*	*	*	*
Located in metropolitan areas		*	*	*	*
Experienced faster population growth than the national average (2000-2005)			*	*	*
Over 250,000 residents in 2000 (Covered by American Community Surveys)				*	*
Waste statistics confirmed at the county level					*
	3,141	**1,100**	**500**	**100**	**39**

In addition to ACS and ACS Supplement Surveys, Current Business Patterns, U.S. EPA databases, as well as county-level web sites also provided data for independent variables of interest. Table 4.3 presents more details. To examine the multicollinearity issue, a bivariate correlation analysis was conducted by implementing a corr command in STATA. As shown in Table 4.4, the results suggest that there are indeed high correlations (with correlation values larger than 0.8) among several pairs of exploratory variables, such as those between total population and white population, population and employment, white population and number of single-family housing units, number of households with one or more people 65 years and over and number of households with householder 65 years and over. Accordingly, this study developed two strategies: (1) conducting test-and-trial regression analyses to identify the variables that result in high F-statistics but undermine the statistical significance of individual coefficients; and (2) including the percentage values of concerned variables instead of the absolute values when applicable. The first step resulted in the exclusion of two variables: employment and number of households with householder 65 years and over. The second step replaced four concerned variables with four new ones. That include: (1) population density, (2) percentage of single-family housing units, (3) percentage of white population, and (4) percentage of households with one or more people 65 years and over. The correlation coefficients among the final selection of exploratory variables are presented in Table 4.5, which no longer suggest a multicollinearity problem.

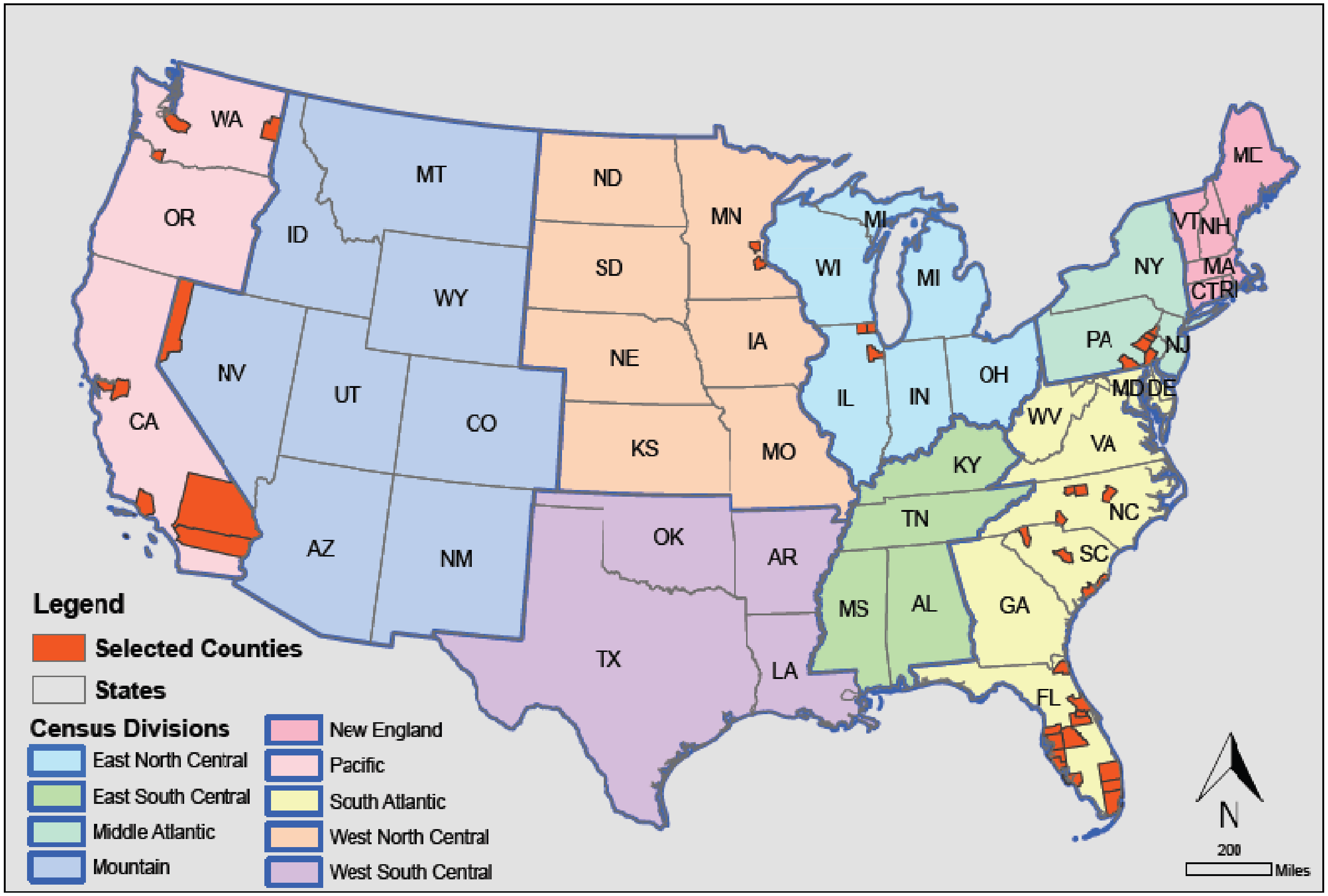

Figure 4.1: Distribution of Selected Counties for This Study

Table 4.3: Definitions and Data Sources of Independent Variables of Interests

Variable Name	Variable Description	Data Source	
		2005	2000
WhitePop	Number of white people	ACS B02001: RACE - Universe: TOTAL POPULATION	ACSSP002. RACE - Universe: TOTAL POPULATION
SFHU	Number of single family housing units	ACS B25024. UNITS IN STRUCTURE - Universe: HOUSING UNITS	ACSSH027. UNITS IN STRUCTURE - Universe: HOUSING UNITS
MeHHIn	Median household income	ACS B19013. MEDIAN HOUSEHOLD INCOME IN THE PAST 12 MONTHS (IN 2005 INFLATION-ADJUSTED DOLLARS) - Universe: HOUSEHOLDS	ACSSP073. MEDIAN HOUSEHOLD INCOME IN THE PAST 12 MONTHS (IN 2000 INFLATION-ADJUSTED DOLLARS) BY AGE OF HOUSEHOLDER - Universe: HOUSEHOLDS
Hher65	Number of households with householder 65 years and over	ACS B19037. AGE OF HOUSEHOLDER BY HOUSEHOLD INCOME IN THE PAST 12 MONTHS (IN 2005 INFLATION-ADJUSTED DOLLARS) - Universe: HOUSEHOLDS	ACSSP017. HOUSEHOLD TYPE BY AGE OF HOUSEHOLDER - Universe: HOUSEHOLDS
MeBldAge	Median Building Age	ACS B25035. MEDIAN YEAR STRUCTURE BUILT - Universe: HOUSING UNITS	ACSSH032. MEDIAN YEAR STRUCTURE BUILT - Universe: HOUSING UNITS
MeTrav	Median commuting time for workers (in minutes)	Calculated using ACS B08012. SEX OF WORKERS BY TRAVEL TIME TO WORK - Universe: WORKERS 16 YEARS AND OVER WHO DID NOT WORK AT HOME	Calculated using ACSSP049. TRAVEL TIME TO WORK BY MEANS OF TRANSPORTATION TO WORK FOR WORKERS 16 YEARS AND OVER WHO DID NOT WORK AT HOME - Universe: WORKERS 16 YEARS AND OVER WHO DID NOT WORK AT HOME

Table 4.3: Definitions and Data Sources of Independent Variables of Interests (continued)

Variable Name	Variable Description	Data Source	
		2005	2000
Emp	Total Mid-March Employment	County Business Pattern 2005 - Fieldname "EMP"	County Business Pattern 2000 - Fieldname "EMP"
PAYT	Number of years Pay-As-You-Throw programs has been fully or partially implemented	US EPA. (1999B). Unit-Based Pricing in the United States: A Tally of Communities.	Waste Management Agency of Each Selected County/Select for Study

Note: (1) ACS: American Community Survey; (2) ACSS: American Community Survey Supplementary Survey; and (3) Median household income data are adjusted by CPI across the years.

Table 4.4: Correlation Matrix of Variables of Interests

	Pop	White	Emp	SFHU	Hhw65yrs	Hher65	MeHHin	MeTrav	MeBldAge	PAYT
Pop	1									
White	0.9854	1								
Emp	0.8931	0.8631	1							
SFHU	0.9826	0.9648	0.8708	1						
Hhw65yrs	0.8892	0.9082	0.7834	0.8656	1					
Hher65	0.8545	0.8771	0.7493	0.8388	0.9952	1				
MeHHin	-0.1492	-0.136	-0.1655	-0.1359	-0.329	-0.336	1			
MeTrav	0.2522	0.2288	0.2988	0.2676	0.1885	0.1804	0.2526	1		
MeBldAge	-0.0959	-0.0956	-0.1417	-0.1211	-0.0934	-0.1109	-0.0322	-0.1808	1	
PAYT	-0.1801	-0.1542	-0.2473	-0.1785	-0.2615	-0.2726	0.4114	0.0308	0.3624	1

Table 4.5: Correlation Matrix of Variables Selected for Panel Data Analysis

	PopDensity	PWhite	PSFHU	PHhw65yrs	MeHHin	MeTrav	MeBldAge	PAYT
PopDensity	1.000							
Pwhite	-0.228	1.000						
PSFHU	-0.084	0.274	1.000					
PHhw65yrs	-0.196	0.292	-0.474	1.000				
MeHHin	0.230	0.167	0.615	-0.530	1.000			
Metrav	0.578	-0.235	-0.068	-0.161	0.253	1.000		
MebldAge	-0.024	0.155	0.345	0.062	-0.032	-0.181	1.000	
PAYT	0.009	0.256	0.507	-0.246	0.411	0.031	0.362	1.000

In terms of waste statistics, there is no one-stop waste management database for every county. Due to time and resource constraints, this study only resorted to publicly accessible data sources. The county-level data were collected mainly from three channels: (1) aggregated data at state agencies, such as the Department of Environmental Protection, (2) solid waste management plans developed by counties and approved by the state agencies, and (3) academic research, which may disclose some additional data through individual surveys. Some jurisdictions only publish the latest reports online but indicate their efforts of compiling data in the same format in the past years. In such a case, phone/email inquiries were conducted for the historical data not accessible online but available to the public upon requests (such as South Carolina).

Although many counties publish waste statistics online, not every county provides adequate information to measure its waste volume "by origin," which is the indicator selected for this study. In addition, considerable inconsistencies in waste statistics exist across jurisdictions, as summarized below.

Definition of MSW

As discussed earlier, there is no uniform definition of MSW at the national level. Some counties count all wastes accepted in the MSW landfills as MSW; some counties may exclude C&D waste, yard waste, and ash.

Definition of Waste Recycling and Diversion

The terms of waste recycling and diversion are not always distinguished. In many cases, they are used interchangeably. Some counties explicitly differentiate waste recycling, recovery, and diversion. For example, Clark County, Washington, considers "recycling" as used materials that are collected and manufactured into "recycled content" product. Materials that are not made into new products are considered as “recovery,” such as construction debris that is crushed and used as aggregate rock substitute. Waste diversion is the sum of waste recycling and recovery (Clark County Solid Waste Management Plan, 2008).

Waste Volume Measurement

Most counties measure waste collected by weight (in tons), but some counties measure them by volume (in cubic yards), such as those in Colorado and Michigan. In some cases, counties measure waste volume in cubic yards and convert it using the industry standard of conversion factor: 1 cubic yard = 3.3 tons (Illinois EPA, 2006).

Data Recording Period

Some counties record data for the fiscal year (such as North Carolina and South Carolina) while some counties use the calendar year. By default, the calendar year method was adopted for this study. For waste statistics based on fiscal year, this study calculated the average of adjacent fiscal years (e.g., 1999-2000 and 2000-2001 for 2000).

Data Update Frequency

While most jurisdictions require annual reporting, waste statistics are not always up to date in the latest report. For example, Kane County of Illinois, the latest report of 2008 still relies on the 2003 data. Such counties are excluded from this study.

Data Reporting Validity and Accuracy

One confounding factor of data mining is the inconsistency in waste statistics when reported in different documents. An example would be Clark County, Nevada. The recycling rate reported in one document (NDEP, 2010) triples the rate in another report (Clark County Health District, 2001) of the same period, year 2001. The State agency noted incomplete reporting from recycling centers and made adjustments (NDCRN, 2003). Thus, cross-reference check of data, when possible, can be very helpful.

Data Reporting Efforts

The last but not the least issue that may not be evident to the public is the range and quality of various data reporting efforts across regions. That is, one region's higher waste generation volume may be an artifact of better systems of data reporting. Likewise, a lower recycling volume (rate) may be an effect of incomplete reporting rather than actual recycling performance.

Thus, the major challenges in carrying out this study were to collect and process waste statistics, and consequently, to incorporate the imperfect and inconsistent datasets. Several counties require manual processing of data, such as aggregating waste statistics by waste management facilities or by geographic jurisdictions (incorporated cities, townships, and unincorporated areas). In addition, multiple data references were sought whenever possible for cross-reference check and collected additional information to select the most reasonable number when needed.

DATA EVALUATION AND PRELIMINARY ANALYSIS

The 39 counties included in this study present a considerable variance in terms of waste management performance. Figures 4.2 to 4.4 present a list of selected counties, ranked by the per capita total waste generation volume, waste disposal volume, and recycling volume, respectively. Particularly in terms of recycling, annual per capita recycling volume varies from about 100 lbs to over 3,000 lbs. Regarding the total waste generation volume, annual per capita generation volume varies from about one ton to over three tons across the selected counties (in 2005). Comparatively speaking, annual per capita waste disposal volume presents less variance across the observed counties, as evidenced by the standard deviation STDV (in Table 4.6), which is a statistical measure of variations from the mean value among observations. Several counties with high waste generation volume also recycled more, which suggest waste generation and recycling volume should be both examined for waste-reduction strategies. In terms of the independent variables, the large STDV for population density across observed counties suggests that additional studies may be needed.

Based on the data collected from the 39 counties discussed above, three pairs of correlation were examined: (1) population growth and waste generation change, (2) population growth and waste disposal volume change, and (3) waste generation and disposal volume changes.

As illustrated in Figure 4.5, although waste generation volume generally increased along with population growth between 2000 and 2005, seven out of the observed 39 counties achieved reduction in waste generation volume. Empirical evidence suggests that waste generation increase indeed can be decoupled from population growth.

Six counties experienced decreases in waste disposal volume between 2000 and 2005 (Figures 4.6 and 4.7). Four of those six counties (Manatee, FL; Guilford, NC; Chester, PA; McHenry, IL) also experienced decreases in total waste generation volume at the same time. The other two counties (Berks, PA and Pasco, FL) achieved a reduction in waste disposal volume, despite an increase in total waste generation. This reverse trend appears to be attributed to sizeable progress in recycling.

To examine the factors that may have contributed to higher recycling rate, PAYT data were examined for the 39 counties included in this study (Table 4.7). By 2000, 14 out of the 39 selected counties implemented PAYT. Between 2000 and 2005, another two counties implemented PAYT. Berks County has implemented PAYT program for over 10 years, but Pasco, FL did not have a PAYT program in place before the study period. Meanwhile, both counties (Berks, PA and Pasco, FL) had an increase in median household income between 2000 and 2005 (an increase of $2,380 and $1,920, respectively). It suggest that a higher affluence level may promote recycling behaviors, while the effectiveness of PAYT programs may need further study, such as the a panel data analysis explained in the following section.

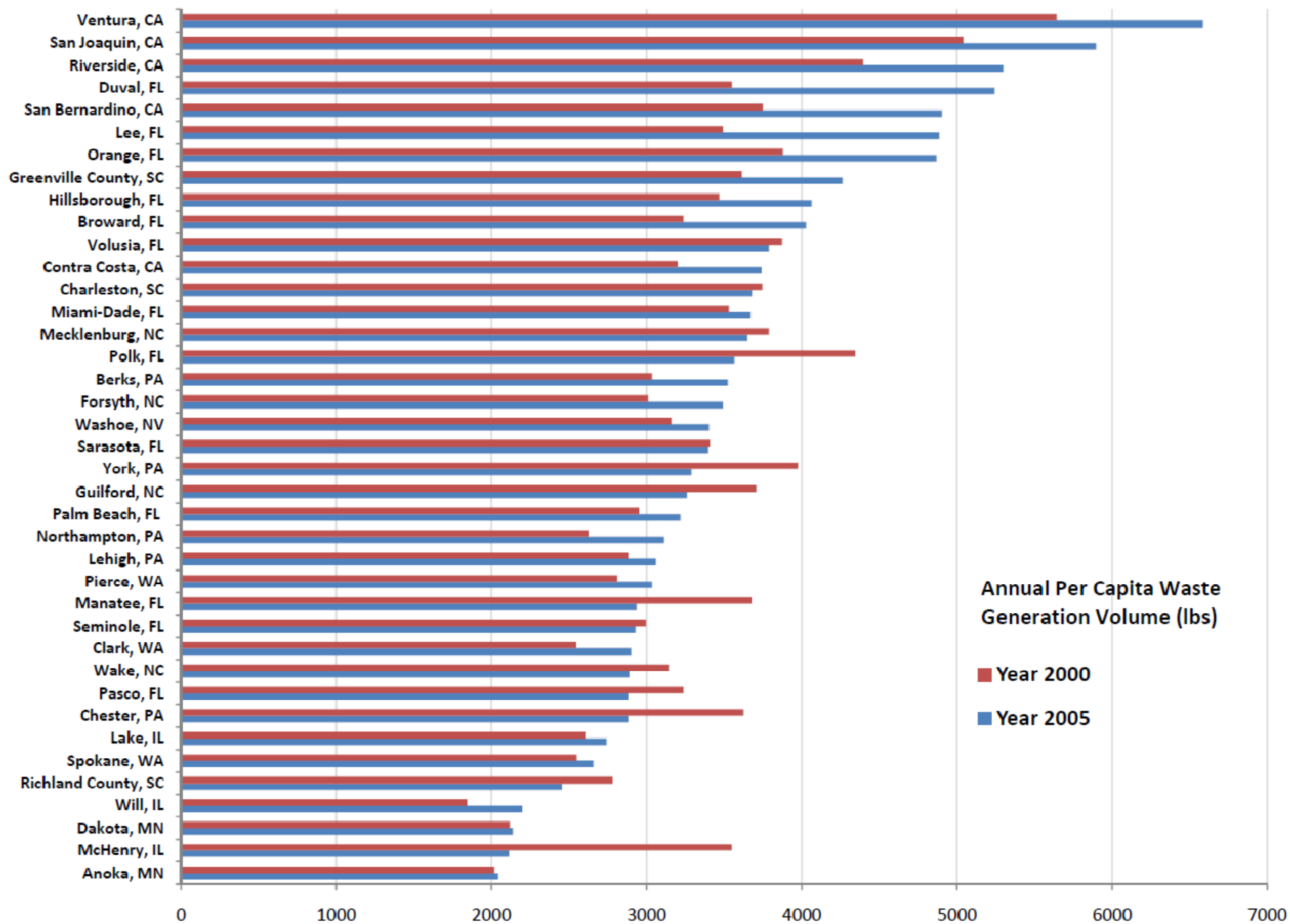

Figure 4.2: Annual per Capita Waste Generation Volume in Selected Counties

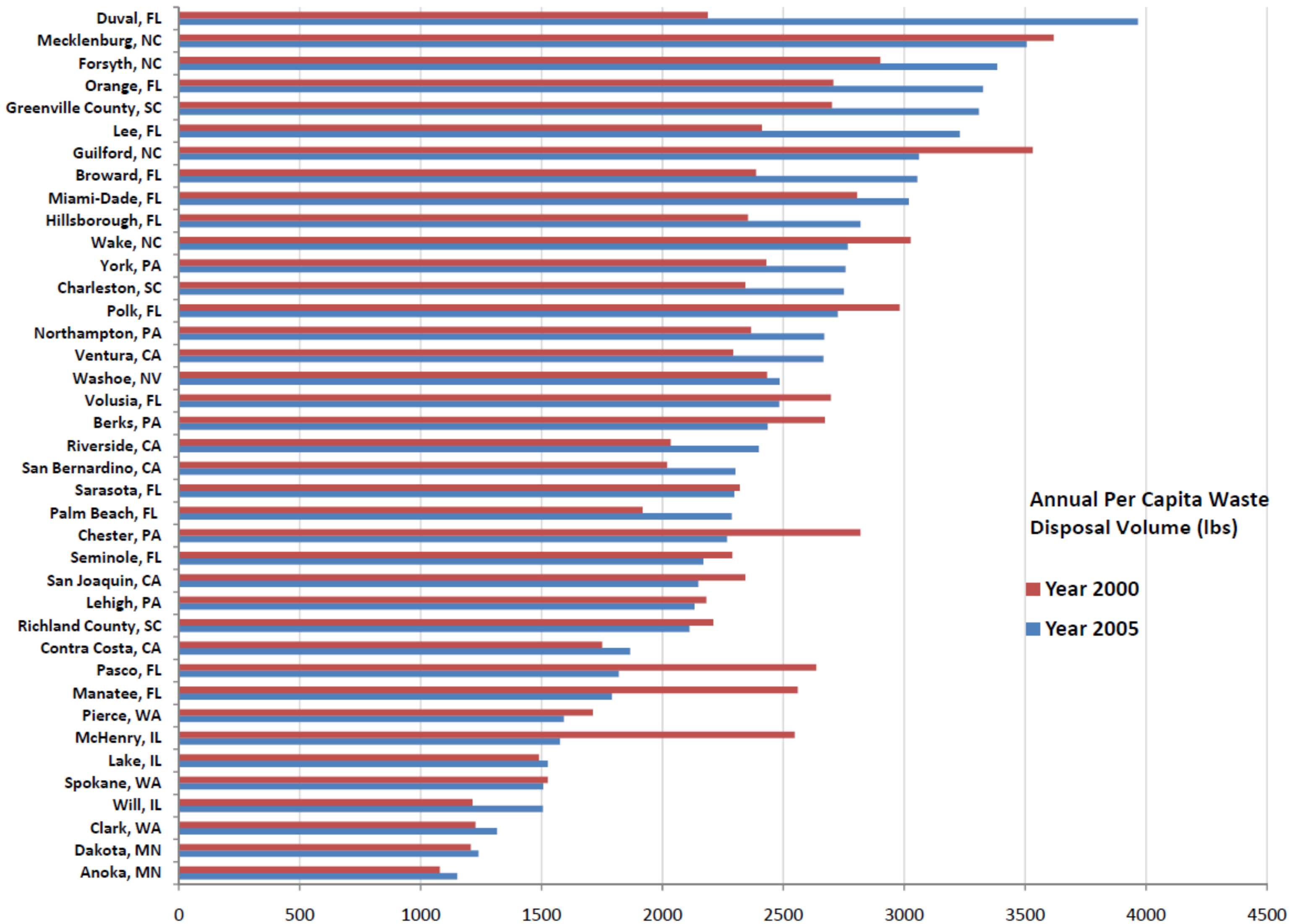

Figure 4.3: Annual per Capita Waste Disposal Volume in Selected Counties

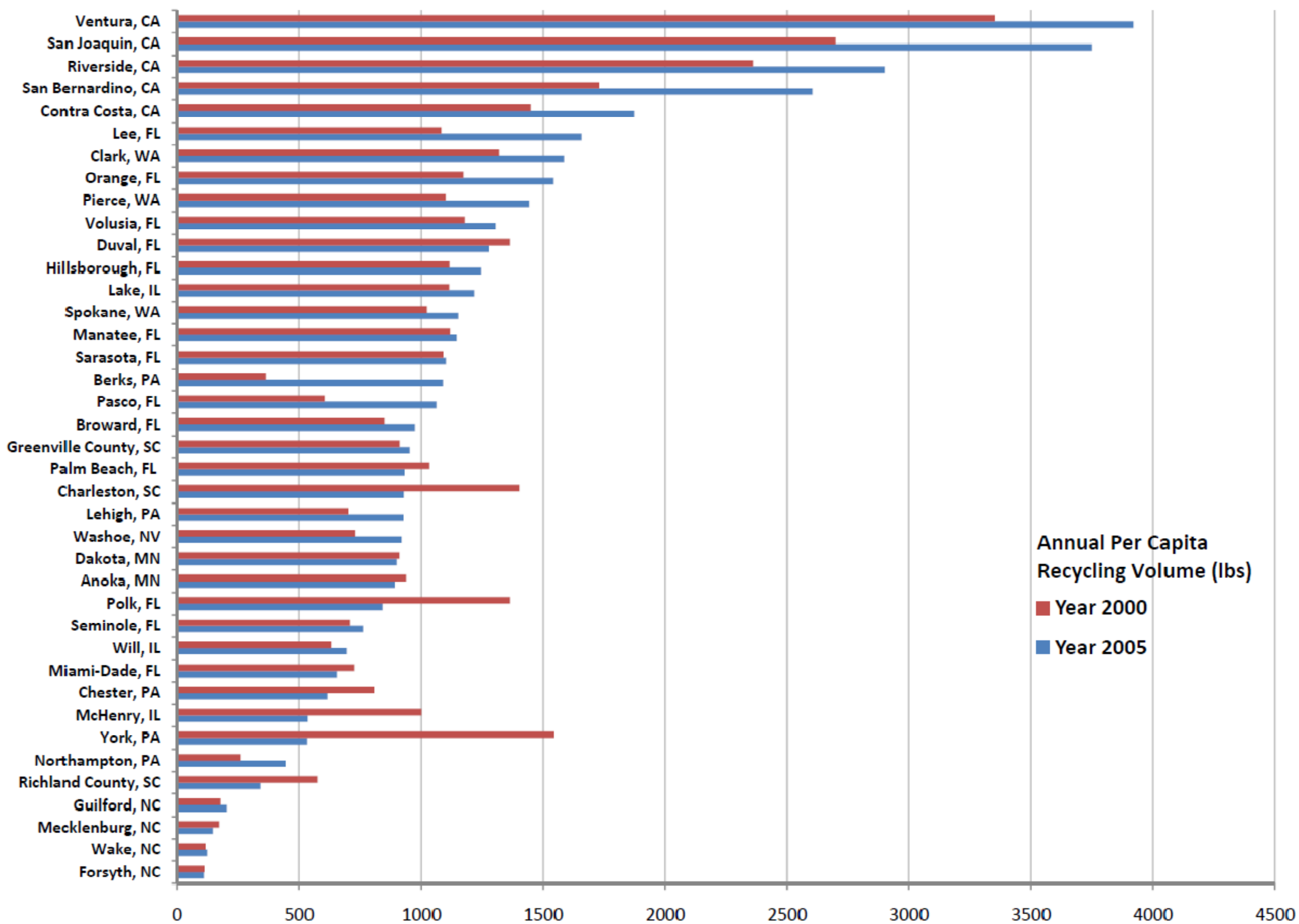

Figure 4.4: Annual per Capita Waste Recycling Volume in Selected Counties

Table 4.6: Summary Statistics of Selected Variables

	2000				2005			
	Mean	**Min**	**Max**	**STDV**	**Mean**	**Min**	**Max**	**STDV**
<u>Dependent Variables</u>								
PRecycle (lbs/year)	1,047	109	3,351	662	1,160	106	3,920	862
PDisposal (lbs/year)	2,306	1,080	3,618	592	2,395	1,152	3,966	691
PTotW (lbs/year)	3,353	1,843	5,643	753	3,555	2,044	6,586	1,045
<u>Independent Variables</u>								
PopDensity (/sq miles)	642	54	1,440	358	713	61	1,570	391
Pwhite (Percentage)	80	51	95	11	77	49	92	12
PSFHU (Percentage)	67	46	83	9	69	49	89	9
Phhw65yrs (Percentage)	24	13	43	8	23	14	42	7
MeHHIn ($1,000)	45	32	68	10	45	33	64	9
MeTrav (Minutes)	21	7	52	9	25	12	75	14
MeBldAge (Years)	24	15	45	7	26	15	45	7
PAYT	0.36	0.00	1.00	0.49	1.85	0.00	5.00	2.40

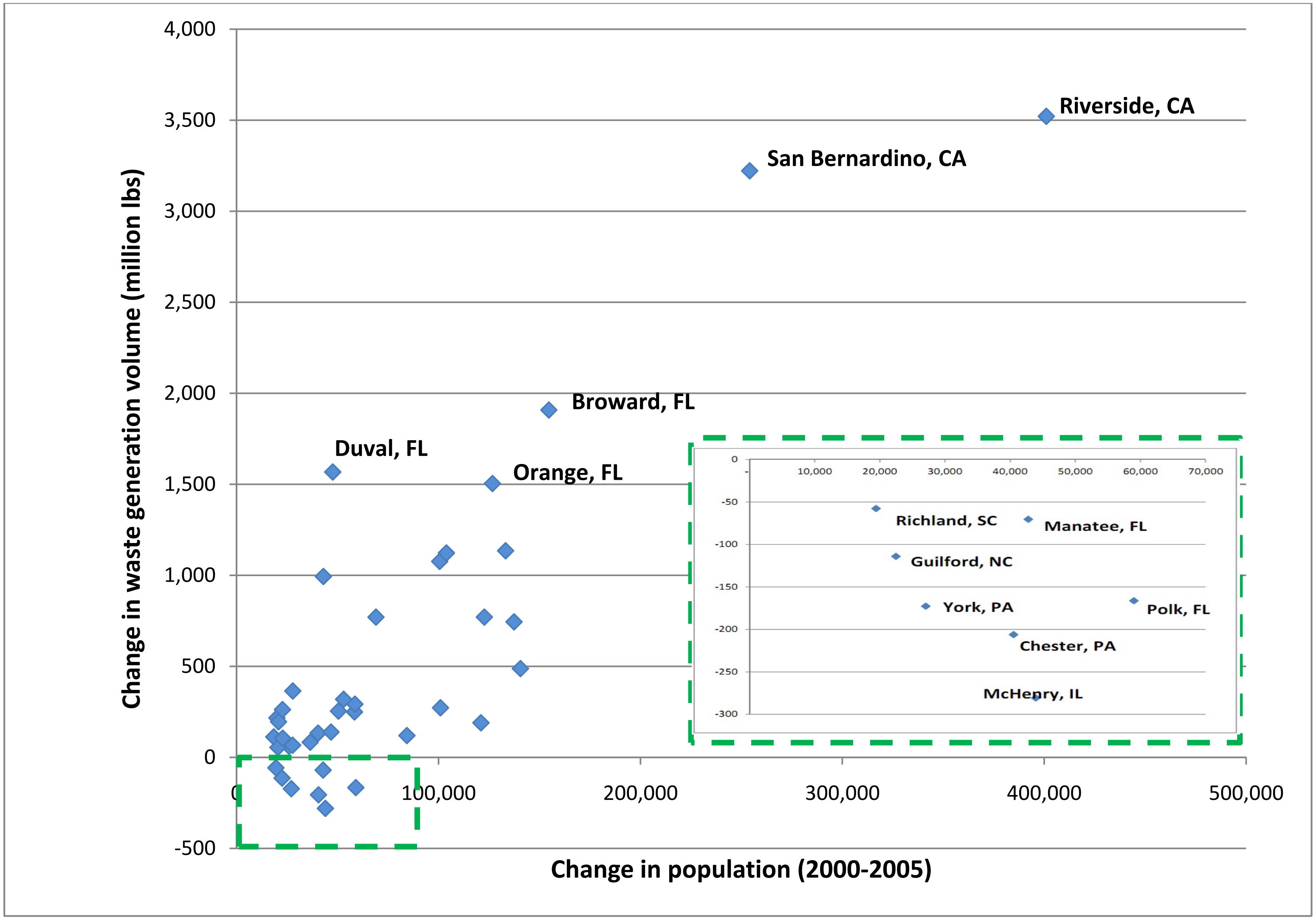

Figure 4.5: Correlation of Population and Waste Generation in Change Terms (2000-2005)

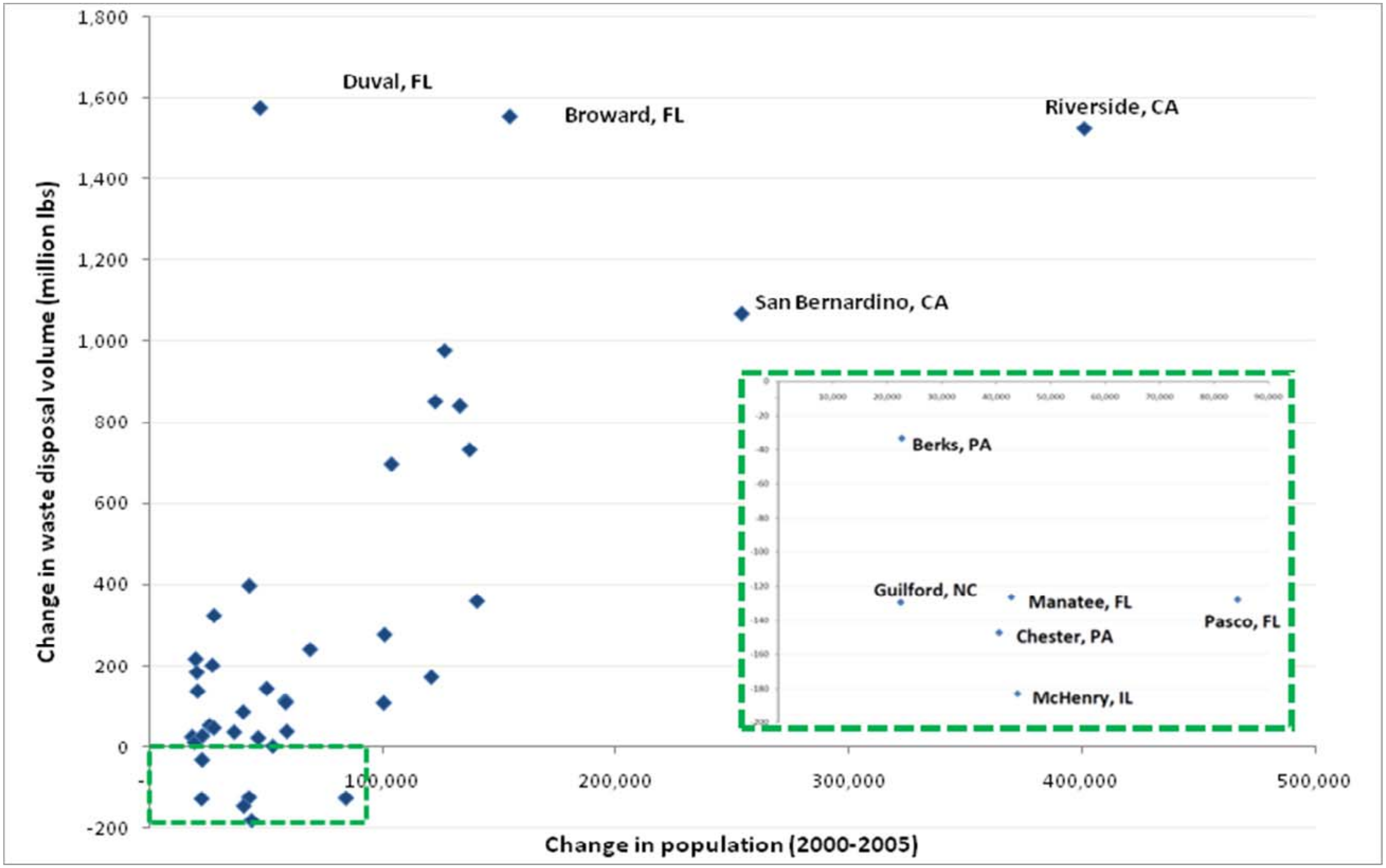

Figure 4.6: Correlation of Population and Waste Disposal in Change Terms (2000-2005)

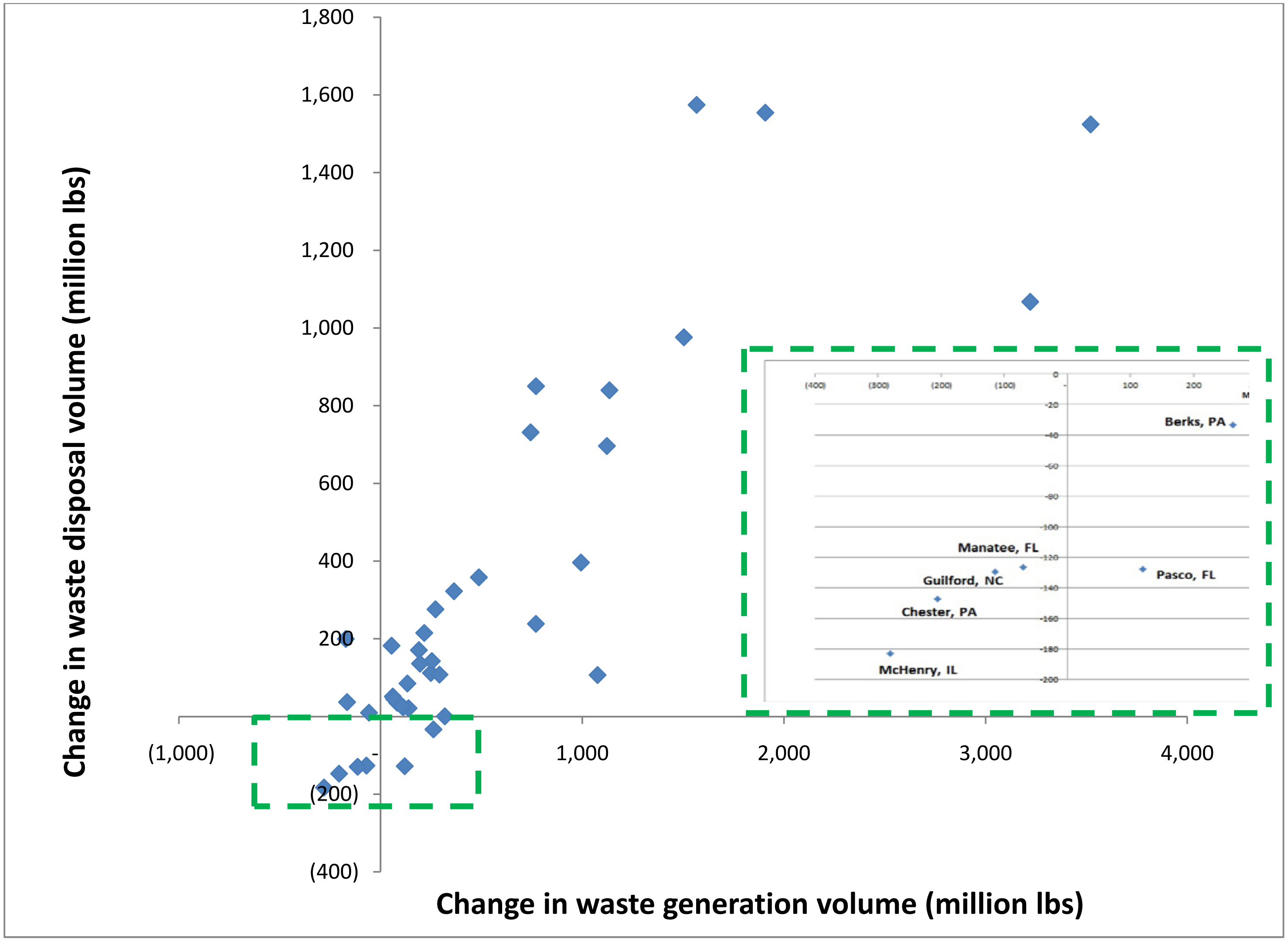

Figure 4.7: Correlation of Waste Generation and Waste Disposal in Change Terms (2000-2005)

Table 4.7: Status of PAYT Program for 39 Counties Selected

	Initiated PAYT in 2000 or earlier	Initiated PAYT 2000 - 2005	Not initiated PAYT as of 2005
Contra Costa, CA	x		
Riverside, CA			x
San Bernardino, CA			x
San Joaquin, CA	x		
Ventura, CA	x		
Broward, FL			x
Duval, FL			x
Hillsborough, FL			x
Lee, FL			x
Manatee, FL			x
Miami-Dade, FL			x
Orange, FL			x
Palm Beach, FL			x
Pasco, FL			x
Polk, FL			x
Sarasota, FL			x
Seminole, FL			x
Volusia, FL			x
Lake, IL	x		
McHenry, IL	x		
Will, IL		x	
Anoka, MN	x		
Dakota, MN	x		
Washoe, NV			x
Forsyth, NC			x
Guilford, NC			x
Mecklenburg, NC			x
Wake, NC			x
Berks, PA	x		
Chester, PA	x		
Lehigh, PA	x		
Northampton, PA		x	
York, PA	x		
Charleston, SC			x
Greenville, SC			x
Richland, SC			x
Clark, WA	x		
Pierce, WA	x		
Spokane, WA	x		

Source: US EPA (1999B) and each county's waste management government web site in table B.2.

RESULTS OF PANEL DATA ANALYSIS

As discussed earlier, the same set of independent variables were used for testing the causal relationship in three regression analyses: (1) per capita waste generation volume; (2) per capita waste disposal volume; and (3) per capita waste recycling volume. The results are presented in Tables 4.8-4.10.

For the dependent variable per capita total waste generation volume (PTotW), both county effects and fixed time effects exist (Table 4.11). Thus, the results of two-way fixed effects model is more valid. The variables that are significant are: percentage of white population (PWhite, negative impact) and median building age (MeBldAge, positive impact). Numerically, for a county with a higher percentage of white population, an increase of 1% in white population corresponds to a waste reduction of 32 lbs on the annual per capita basis. A county with older buildings, in the case of one year older of the median building age, corresponds to a waste generation increase of 84 lbs.

For the dependent variable per capita disposal volume (PDisposal), county effects are significant, but fixed time effects are not. Thus, the results of one-way fixed effects model and two-way fixed effects model show similar results. Two variables are significant in both models: PAYT (negative impact) and percentage of white population (PWhite, negative impact).A city that does not charge households by waste volume corresponds to an increase in waste disposal of 76 lbson the annual per capita basis. Again, a higher percentage of white population corresponds to a lower volume of waste disposal.

For dependent variable per capita recycling volume (PRecycle), both county effects and time effects are significant. Thus, the results of two-way fixed effects model are considered more valid. Two variables that are significant are: PAYT (positive impact) and median household income (MeHHin, positive impact). A county that does not charge households by waste volume corresponds to a decreased recycling volume of 61 lbs on the annual per capita basis. A county with wealthier households, an increase of $1,000 in median household income corresponds to an increase of 41 lbs recycling materials per capita per year.

SUMMARY AND DISCUSSIONS

On the basis of empirical data across 39 counties in the U.S., this study found that population growth did not necessarily result in increases in waste generation. Six counties in different states achieved waste reduction even when its population growth was higher than the national average between 2000 and 2005.

In terms of the causal factors for waste reduction, economic incentives proved to be effective. Charging households by the volume of their waste generation helps increase recycling and reduce waste disposal. In addition, counties with a higher percentage of white population tends to generate less waste and those with higher median household income recycled more. Counties with older buildings generate more waste.

The positive correlations between median building age and waste generation can be attributed to several indicators of importance to planning. First, older buildings may need more maintenance and generate more waste. Second, older counties are frequently business centers with a high density of employment. While employment and residence may not be always located in the county, waste generated from commercial, institutional, and non-hazardous industrial activities may all contribute to a high rate of waste generation on the per capita basis. Thus, the indicator may also reflect an omitted variable here: employment size, which was excluded because of its high correlation with population size. In sum, the challenges of counties with a longer history may face greater challenges of municipal solid waste management.

The empirical findings suggest that public policy could play a role in waste reduction and should resume a stronger presence in waste management. Because of data and resource constraints, this study has limited to the single-stream MSW. Future extension of this research would be to divide wastes by material types and by generators, and to explore region and material specific waste management methods. Another future direction of research is to refine the unit of analysis at a level smaller than county level, where the accuracy of data entries and adequacy of measurements has created a major research challenge at present.

Table 4.8: Results for Annual Per Capita Waste Generation Volume

	One-way fixed effects				Two-way fixed effects			
	Coefficient	**Robust standard error**	**t-value**	**Prob>|t|**	**Coefficient**	**Robust standard error**	**t-value**	**Prob> |t|**
PAYT	-48.13	45.74	-1.05	0.301	-15.58	54.62	-0.29	0.777
PopDensity	0.42	1.30	0.33	0.747	2.79	1.90	1.47	0.153
Pwhite	-2737.07	1955.07	-1.40	0.171	-3187.91	1724.12	-1.85	0.074*
PSFHU	4419.09	4261.95	1.04	0.308	4768.32	4536.79	1.05	0.302
Phhw65yrs	-3472.44	7320.84	-0.47	0.639	-3527.56	7227.12	-0.49	0.629
MeHHIn	24.77	32.66	0.76	0.454	37.54	35.76	1.05	0.302
MeTrav	-0.53	8.45	-0.06	0.950	0.80	8.61	0.09	0.926
MeBldAge	42.81	43.15	0.99	0.329	84.15	39.44	2.13	0.041*
Heteroskedasticity	R-squared = 0.9010 Adjusted R-Square = 0.7540 chi2(1) = 1.01 Prob> chi2 = 0.3161				R-squared = 0.9050 Adjusted R-Square = 0.7561 chi2(1) = 0.69 Prob> chi2 = 0.40			

*Note: * , **, and *** denote significant at the 10%, 5% , and 1% level respectively.*

Table 4.9: Results for Annual Per Capita Waste Disposal Volume

	One-way fixed effects				Two-way fixed effects			
	Coefficient	**Robust standard error**	**t-value**	**Prob>|t|**	**Coefficient**	**Robust standard error**	**t-value**	**Prob> |t|**
PAYT	-71.63	33.53	-2.14	0.041**	-76.57	38.94	-1.97	0.059*
PopDensity	0.24	1.21	0.20	0.843	-0.12	2.01	-0.06	0.954
Pwhite	-2375.65	1242.05	-1.91	0.065*	-2307.23	1143.42	-2.02	0.053*
PSFHU	3859.18	2795.61	1.38	0.177	3806.17	2847.15	1.34	0.191
Phhw65yrs	2040.06	6045.07	0.34	0.738	2048.42	6114.38	0.34	0.740
MeHHIn	-1.52	28.14	-0.05	0.957	-3.45	32.37	-0.11	0.916
MeTrav	0.68	6.79	0.10	0.921	0.48	7.23	0.07	0.947
MeBldAge	17.50	39.75	0.44	0.663	11.22	46.79	0.24	0.812
	R-squared = 0.8771 Adjusted R-Square = 0.6974				R-squared = 0.8772 Adjusted R-Square = 0.6849			
Heteroskedasticity	chi2(1) = 10.51 Prob> chi2 = 0.0012				chi2(1) = 10.37 Prob> chi2 = 0.0013			

*Note: * , **, and *** denote significant at the 10%, 5% , and 1% level respectively.*

Table 4.10: Results for Annual Per Capita Waste Recycling Volume

	One-way fixed effects				Two-way fixed effects			
	Coefficient	**Robust standard error**	**t-value**	**Prob>|t|**	**Coefficient**	**Robust standard error**	**t-value**	**Prob> |t|**
PAYT	23.45	45.90	0.51	0.613	61.00	35.73	1.71	0.098*
PopDensity	0.18	0.81	0.22	0.825	2.91	1.82	1.60	0.120
Pwhite	-364.39	1746.45	-0.21	0.836	-884.38	1477.52	-0.60	0.554
PSFHU	561.58	2361.26	0.24	0.814	964.37	2601.64	0.37	0.713
Phhw65yrs	-5503.08	4170.38	-1.32	0.197	-5566.65	3451.81	-1.61	0.117
MeHHIn	26.27	19.40	1.35	0.185	41.00	21.17	1.94	0.062*
MeTrav	-1.21	4.69	-0.26	0.797	0.32	4.84	0.07	0.947
MeBldAge	25.26	44.82	0.56	0.577	72.93	52.47	1.39	0.175
	R-squared = 0.9530 Adjusted R-Square = 0.8832				R-squared = 0.9606 Adjusted R-Square = 0.8988			
Heteroskedasticity	chi2(1) = 2.93 Prob> chi2 = 0.0867				chi2(1) = 1.05 Prob> chi2 = 0.3060			

*Note: * , **, and *** denote significant at the 10%, 5% , and 1% level respectively.*

Table 4.11: F-test for Fixed Effects

Dependent Variables	Annual Per Capita Waste Generation Volume (PTotW)	Annual Per Capita Waste Disposal Volume (PDiscard)	Annual Per Capita Recycling Volume (Precycle)
***F*-test for county effects**	$F(38, 31) = 5.10$*** Prob>F = 0.0000	$F(38, 31) = 2.98$*** Prob>F = 0.0012	$F(38, 31) = 11.88$*** Prob>F = 0.0000
***F*-test for time effects**	$F(1, 38) = 1.27$ Prob> F = 0.2683	$F(1, 38) = 0.05$ Prob> F = 0.8320	$F(1, 38) = 5.77$** Prob>F = 0.0227

CHAPTER 5

IMPACT OF WASTE MANAGEMENT ON ECONOMIC DEVELOPMENT

The empirical analysis in Chapter 4 demonstrated that cost considerations matter in terms of waste management decision making. It further leads to some practical and important questions: whether landfill disposal can be the most cost-effective option for an urban region to manage its waste, assuming it would have adequate landfill capacity? Should promoting landfills be an economic strategy to promote distressed areas? If yes, under what conditions?

This chapter addresses these questions in an empirical analysis that compares the cost-effectiveness of pro-landfilling activities to other waste management options, using a full cost accounting approach. While this study provided an economic analysis of waste management in general, many discussions centered on landfill disposal activities, which continued to be the primary method of solid waste disposal in the U.S., regardless of the commonly perceived pollution to the air, water, and land (El-Fadel et al., 1997; U.S. EPA, 2009).

RESEARCH DESIGN

Because of regional variations in waste management operations, a cost-effective analysis has to be region specific. California was chosen to be the context of this simulation study because the state is one of the most advanced in waste management and has progressively enacted legislations to promote waste reduction and diversion from landfills. California has achieved 52% waste diversion rate, compared to 34% as the national average (CIWMB, 2009; U.S. EPA, 2010). It published the first comprehensive economic impact analysis of both waste disposal and diversion analysis (Goldman and Ogishi, 2001), which provides a valuable opportunity for researchers to examine both direct and indirect costs of waste management options. Because of data constraints, the purpose of this study was not to provide precise information for pricing decisions. Rather, by incorporating the life cycle costs of different waste management options, this study aimed to discover the cost differentials to a local community in the long run, i.e., a 50-year period.

This study compared five options for a county in California to manage its waste: (1) siting a new landfill; (2) expanding the capacity of an existing landfill; (3) exporting the waste; (4) promoting recycling and reuse; and (5) waste-to-energy (WTE). The focus was to compare pro-landfilling activities to other established waste management options. Because neither waste-to-energy facilities nor recycling markets are strong enough to manage the total waste stream independently, this study considered "hybrid" scenarios - e.g., 50% WTE and 50% landfilling; and 50% recycling and 50% landfilling. The scenarios of 50-50 split between waste management methods were selected with considerations of both technical and economic feasibilities, compared to the best practice in both European counties and the U.S. While WTE has seen increasing popularity in the U.S. lately for energy recovery, not 100% of MSW can be burned in WTE facilities. Technically, not all types of waste have high heat value (such as food waste and yard trimmings, which together account for nearly 30% of MSW stream). In addition, WTE does not eliminate waste completely;the residuals (ash) still need to be landfilled. Thus, a 50-50 split between WTE and landfills can be a reasonable plan. In terms of recycling, not every type of waste has secondary market value and not everyone participates in recycling. A couple of EU countries such as Belgium, Germany, and the Netherlands, which are considered the most advanced in waste management, have reached 60%-70% recycling rate, (Eurostat, 2007; Friends of Earth Europe, 2009). On average, only 34% of MSW are currently recycled in the U.S. (U.S. EPA, 2010). This study assumed a 50% recycling rate in the California region, which is about the level of current performance (52%). This is also consistent with the target rate of waste diversion set in the California Integrated Waste Management Act, Assembly Bill 939 (California State Assembly, 1989).

Ideally, other scenarios would also be considered to include recent developments in the technology of waste management. Because such market is underdeveloped and current literature presents a sizeable range of cost and benefit, this study assumed that the impacts of those new technologies are minimal at this stage and thus did not include in the scenarios.

In a system view of each waste management option, this study adopted a full cost accounting approach, which aimed to include all the costs associated with providing a particular waste management service throughout the production process (National Recycling Coalition, 1996). For instance, the costs for landfilling include pre-construction costs, construction costs, operating, maintenance, closure and post-closure care, as well as social and environmental impacts. This study also took into account the "multiplier effects" created through inter-sectoral linkages. The indicator of "value added" included in the analysis, in particular, measures the demand of goods and services for waste management activities from other sectors (Goldman and Ogishi, 2001). To incorporate the concerns about externalities, this study also considered environmental damage costs of waste disposal. While previous studies revealed a broad range of damage estimates, as discussed by Eshet (2005), this study chose a lower bound of estimate, \$0.5/ton-\$1/ton, which is consistent with the current level of compensation fees to host communities. Because of data constraints, this study assumed that impacts omitted in this study are negligible, such as the environmental impacts of waste transportation. Such assumptions present a conservative estimate of landfill cost and may be an underestimate.

To incorporate the cost considerations discussed above, this study developed a three-step analysis (illustrated in Figure 5.1). The first step only focused on the short-term costs, or one-time direct costs, such as waste collection cost, waste transportation cost, and waste processing cost, which are the most visible and straightforward costs of waste management activities. Specifically, short-term analysis is limited to a study period of 20 years, which is approximately the average landfill capacity. The next step included the costs along the entire life cycle of waste management operations. Besides the cost items included in Step 1, Step 2 included costs that would occur after the waste is disposed, such as landfill maintenance and post-closure care. To investigate the interaction of short-term and long-term costs, the cumulative net present cost of year i ($1 \leq i \leq 50$) for managing one ton of waste at year 1 was calculated at an assumed discount rate of 3.5%. Further, step 3 included indirect impacts, such as multiplier effects and externality costs.

This study did not differentiate public or private ownership of the waste management facility or the operations. Thus, it did not divide costs into public or private costs. Instead, the costs are calculated at each stage of the production for the county that manages its waste. For example, the costs of holding public meetings and addressing public opposition to hosting waste management facilities were included in the "pre-construction costs."

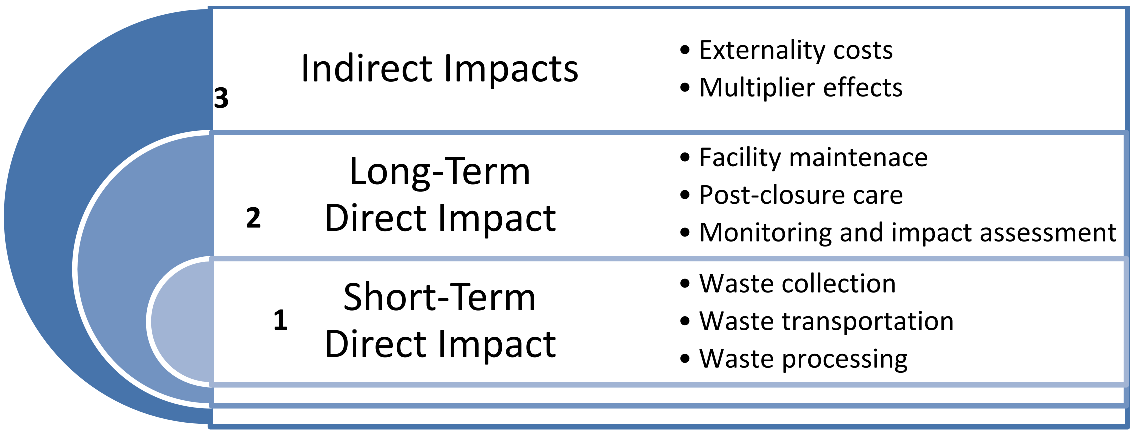

Figure 5.1: Three-Step Cost Effectiveness Analysis of Waste Management Options

DATA AVAILABILITY AND ASSUMPTIONS

The data on the cost of waste management activities is limited and the available data have a wide range of variations for the selected variables. Divergence in cost estimates may result from technical as well as regional variations in production factors, such as land supply and transportation access. It also tends to be subjective depending on the view of data providers. For example, the waste-exporters and private industries represented by the National Solid Waste Management Association generally specify a higher private cost of landfill construction and operation, and do not specify the risks to hosting communities. They claim that waste-importing activities generate revenue and improve social welfare to the local economy (NSWMA, 2001). In contrast, environmental advocates and academic researchers suggest various levels of loss to the hosting community.

When there are uncertainties in data inputs, an average value was determined and adopted. To ensure data consistency, data were collected from California whenever possible. Data from other regions were compared and adopted with an average value, if there was a data gap. Details of the costs and revenues for each waste management option from the literature review are presented in Table 5.1 Based on the information in Table 5.1, Table 5.2 presents a summary of each cost and revenue component, where "-" denotes a cost item while a "+" denotes revenue.

In addition, based on literature review, this study developed the following assumptions for each waste management scenario:

Siting a New Landfill

The average landfill has a capacity of 20 years. It requires approximately 40 acres of land and can hold 25,000 tons of waste per acre. The cost of transporting one ton of collected MSW to the new landfill is $10.

Expanding the Capacity of Existing Landfills

An existing landfill is expanded to 50,000 tons per acre with waste compression technology. The cost of transporting one ton of collected MSW to the landfill site is $10.

Exporting Waste

The transportation cost of long-distance hauling is $0.15/ton-mile. The average exporting distance is 200 miles. The environmental impacts of transportation are most exerted on communities outside the waste generation region, and thus are not included for this study for a consistent boundary of analysis.

Table 5.1: Data Sources and Notes for Waste Management Options

Impact Type	Exporting	Expanding capacity	Siting new landfill	Recycling	Waste to Energy
Capital cost for construction ($/acre for landfill; $/ton for recycling)			$300,000 ~ $800,000 per acre and over $1 million per site pre-construction cost (Duffy, 2005)	$7 million for a recycling processing center with processing capacity at 90 tons/day of mixed recycled materials (Arcata and Eureka Community Recycling Centers, 2007)	A WTE plant with 910,000 ton/year has a capital cost of $61.56/ton at a capacity factor of 0.83. (Klein, 2003)
Landfill capacity expansion cost ($/acre)		$255,000 per acre (Shaw Environmental, 2007).			
Collection cost ($/ton)	$100-$130/ton (Diaz, 2005)	$100-$130/ton (Diaz, 2005)	$100-$130/ton (Diaz, 2005)	$89-$278/ton (U.S. EPA, 2010)	$100-$130/ton (Diaz, 2005)
Processing cost ($/ton)		$3/ton (Duffy, 2005)	$3/ton (Duffy, 2005)	$100-150/ton (El Dorado County Environmental Department Web site, updated in 2008; Pennsylvania EPA, 2005)	$30/ton (Klein, 2003)
Transportation cost ($/ton)	Assumption: $0.15/ton-mile for a transportation distance of 200 miles.	Assumption: $10/ton.	Assumption: $10/ton.	Assumption: $10/ton.	Assumption: $10/ton.
Tipping fees ($/ton)	Average at $44/ton (Haaren, 2010)	Average at $44/ton (Haaren, 2010)	Average at $44/ton (Huaaren, 2010)	Average at $15.4/ton (= $44*35%). Assume $35% of MSW collected do not have significant recovery value and needs to be landfilled - the author's estimates based on U.S. EPA (2010).	Average at $68/ton (Haaren, 2010)

Table 5.1: Data Sources and Notes for Waste Management Options (continued)

Impact Type	Exporting	Expanding capacity	Siting new landfill	Recycling	Waste to Energy
Recycling Revenue				Weighted average of recovery value of MSW. More details in Table C.1.	$30/ton (Klein, 2003)
Ash landfill cost for WTE					$12/ton of waste processed by WTE. 0.15 to 0.25 ton of ash generated for each ton of MSW processed using WTE. (WTERT, 2010)
Value Added ($/ton)	$144 /ton statewide benefits (Goldman and Ogishi, 2001)	$144 /ton statewide benefits (Goldman and Ogishi, 2001)	$144 /ton statewide benefits (Goldman and Ogishi, 2001)	$290 /ton statewide benefits (Goldman and Ogishi, 2001)	Assumption: $144/ton statewide benefits
Maintenance cost (recurring during operation) ($/ton)		$3/ton (Duffy, 2005)	$3/ton (Duffy, 2005)		
Landfill closure cost ($/acre)		$227,000 -$326,000 per acre (Duffy, 2005)	$227,000 -$326,000 per acre (Duffy, 2005)		
Landfill post-closure care (recurring 30 years) ($/acre)		$64,000-$88,000 per acre (Duffy, 2005)	$64,000-$88,000 per acre (Duffy, 2005)		

Table 5.1: Data Sources and Notes for Waste Management Options (continued)

Impact Type	Exporting	Expanding capacity	Siting new landfill	Recycling	Waste to Energy
External cost due to emissions from landfill/incinerator		Cumulative Net Present Cost (NPC) is estimated to be within a wide range of $0.91/ton to $44/ton in various studies (Eshet, 2005). This dissertation assumed that the cost is evenly distributed in a 50-year period. For sensitivity analysis, this dissertation assumed a low value of $0.02/ton per year; an average value of $0.45/ton per year; and a high value of $0.88/ton per year (all values in NPC)	Cumulative Net Present Cost (NPC) is estimated to be within a wide range of $0.91/ton to $44/ton in various studies (Eshet, 2005). This dissertation assumed that the cost is evenly distributed in a 50-year period. For sensitivity analysis, this dissertation assumed a low value of $0.02/ton per year; an average value of $0.45/ton per year; and a high value of $0.88/ton per year (all values in NPC)		The cost is estimated to be within a wide range of $1.3/ton to $171/ton in various studies (Eshet, 2005). For sensitivity analysis, this dissertation assumed a low value of $1.3/ton; an average value of $86.15/ton; and a high value of $171/ton.

Table 5.2: Direct and Indirect Cost Estimates for Different Waste Management Methods

Impact Category	Impact Type	Export	Expand Capacity	Site New Landfill	Promote Recycling	Waste to Energy
One time	Capital annuity payment for facility construction ($/ton)		-15.6	-21.0	-14.24 (at a capacity factor of 0.75)	-68.13 (at a capacity factor of 0.75)
	Landfill closure cost ($/ton)		-5.5	-11.0		
	Collection Cost ($/ton)	-115.0	-115.0	-115.0	-180.0	-115.0
	Processing Cost ($/ton)		-3.0	-3.0	-125.0	-30.0
	Transportation cost ($/ton)	-30.0	-10.0	-10.0	-10.0	-10.0
	Tipping fees ($/ton)	-44.0	44.0	44.0	-15.0	68.0
	Recycling/WTE Revenue ($/ton)				113.0	30.0
	Ash disposal for WTE ($/ton)					-12.0
	Value added ($/ton)	144.0	144.0	144.0	290.0	144.0
Recurring	Maintenance cost (recurring during operation period) ($/ton)		-3.0	-3.0		
	Landfill post-closure care (recurring 30 years) ($/ton)		-1.8	-2.6		
	Environmental cost (recurring 50 years) ($/ton)		-0.5	-0.5		-1.0

Note: Table 5.1includes data sources and additional notes.

Recycling Waste

Recycling revenue can be generated from secondary market sales. Not all MSW has a significant recovery value; the materials that do not have a stable reselling market need to be landfilled and thus incur tipping fees. To process the increasing volume of recyclables, the county needs to build a new recycling processing center. The cost of transporting one ton of collected recyclables to the new recycling facility is $10.

Waste-to-Energy

The revenue of waste-to-energy includes the value of the electricity generated and the sale of recovered metal (Klein, 2003). To implement waste-to-energy (WTE), the county needs to construct a WTE plant. The cost of transporting one ton of collected recyclables to the new recycling facility is $10.

RESULTS AND DISCUSSIONS

This study investigated the costs of five waste management options: siting a new landfill, expanding landfill capacity, 50% siting a new landfill and 50% WTE, 50% siting a new landfill and 50% recycling, and exporting waste. This study covered a cost period of 50 years and calculated the cumulative net present costs (NPCs) of year *i* ($1 \leq i \leq 50$) for managing one ton of waste at Year 1. As depicted in Figure 5.2, while all the waste management options incur direct costs in the short term, pro-landfilling activities seem to incur the lowest cost. Expanding the existing landfill seems to be the most economical option, while recycling and WTE appears to be the most expensive alternative, especially at the beginning of the period due to its high start-up costs. Compared to other waste management approaches, landfills incur lower construction cost and waste processing cost, which is partially determined by the existing economies of scale. This cost difference among waste management options helps explain why expanding a landfill has been more frequently adopted by municipalities than promoting recycling programs.

In the long run, waste management costs need to include landfill closure cost, post-closure care, and recurring maintenance costs. As illustrated in Figure 5.2, the costs of landfilling activities continue to increase over the years and become more costly due to recurring maintenance fees and post-closure costs. As a result, four waste management methods (siting a new landfill, expanding landfill capacity, 50% siting a new landfill and 50% WTE, and 50% siting a new landfill and 50% recycling) incur waste management cost in the same order in the long run (between $200/ton and $230/ton).

Due to the one-time landfill closure cost, there is a bump in the cumulative NPCs at Year 20 for pro-landfilling activities. The cumulative NPCs for exporting does not vary over the years because all the direct costs associated with exporting waste are one-time costs incurred at the year of waste disposal. While export appears to be a cost effective option, it is only an intermediate method of waste disposal; its cost is heavily dependent on fuel prices and landfill tipping fees in other regions, as well as interstate waste flow regulations.

Next, this study included indirect impacts in the cost calculation of waste management options. Indirect impacts may include both revenues/benefits and costs. For example, recycling may generate indirect revenues and benefits in the form of a net gain of income, revenue and job opportunities through backward and forward linkages of recycling activities in a region's economy, or what regional economists call "multiplier effects." In contrast, landfills may generate indirect cost in both environmental and social terms. This study mainly focused on external costs of emissions from landfill/incineration and of property tax loss due to the value depreciation of housing close to landfill facilities.

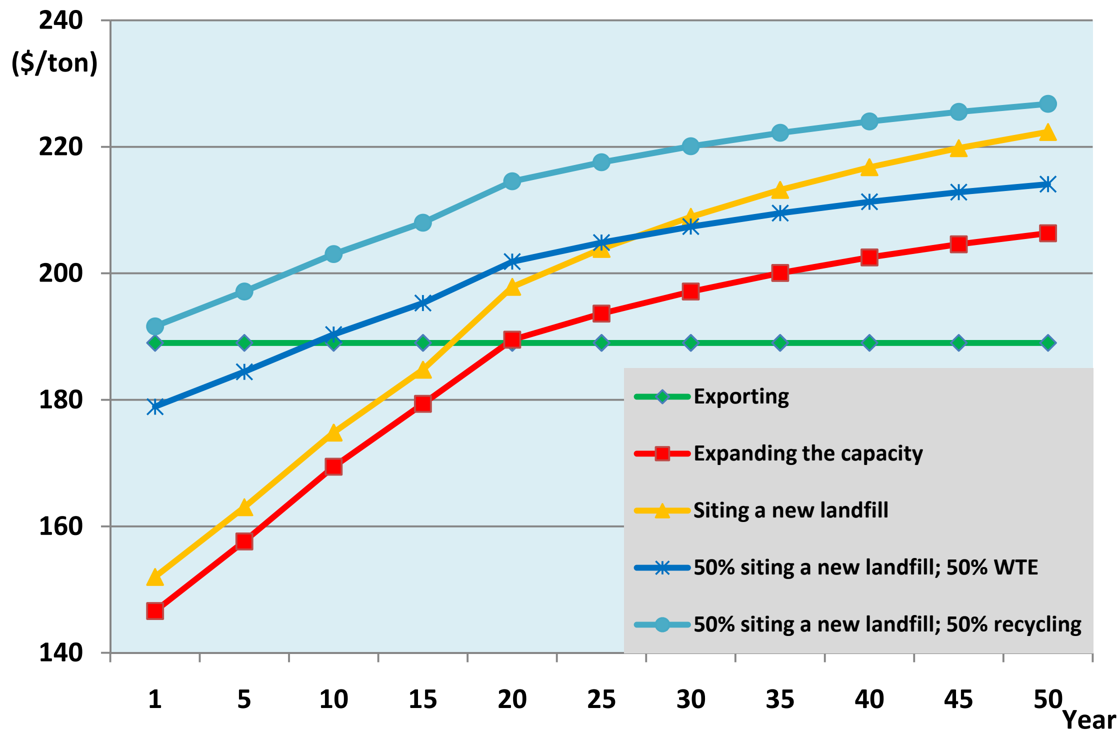

Figure 5.2: Cumulative Net Present Cost through MSW Management Life Cycle

Source: Author calculation based on data in Tables 5.1-5.2.

Many studies have investigated the external costs of landfill and waste-to-energy incinerators. However, as discussed in Chapter 3, previous studies suggested a wide range of cost estimates. For instance, the external cost of incinerators was estimated to be between $1/ton to $171/ton in various studies (Eshet, 2005). The uncertainty in estimates can be caused by several reasons, such as differences in: (1) geographic locations of the studies, (2) estimate methods, and (3) factors included in the external cost estimates (Eshet, 2005).

To address the impact of uncertainties in the estimates of external costs, this study included a sensitivity analysis by using different values of external costs (presented in Table C1 and C2). Figure 5.3 compares the five waste management methods with the average values of external costs obtained from existing studies as the baseline result. Figure 5.4 and Figure 5.5 illustrate the results with low and high values of external costs, respectively. This study found that:

(1) In all three cases of sensitivity analysis, recycling consistently helped reduce the cost of waste management compared to other options. When taking into account the multiplier effects and environmental damage cost, the option with 50% recycling outperforms other options significantly in the long run. The difference between the option with 50% recycling and the most costly option is between \$70/ton to \$145/ton, depending on the values of external costs used.

(2) The external cost of emissions from incineration varies significantly. If an average (\$86/ton) or an upper bound of estimate is adopted (\$171/ton) is adopted, the option with 50% waste-to-energy incurs the highest cost among all five methods. If a lower bound is adopted (\$1/ton), the option with 50% waste-to-energy can incurs less cost than siting a new landfill in the long run.

(3) Expanding landfill capacity incurs lower cost than siting a new landfill.

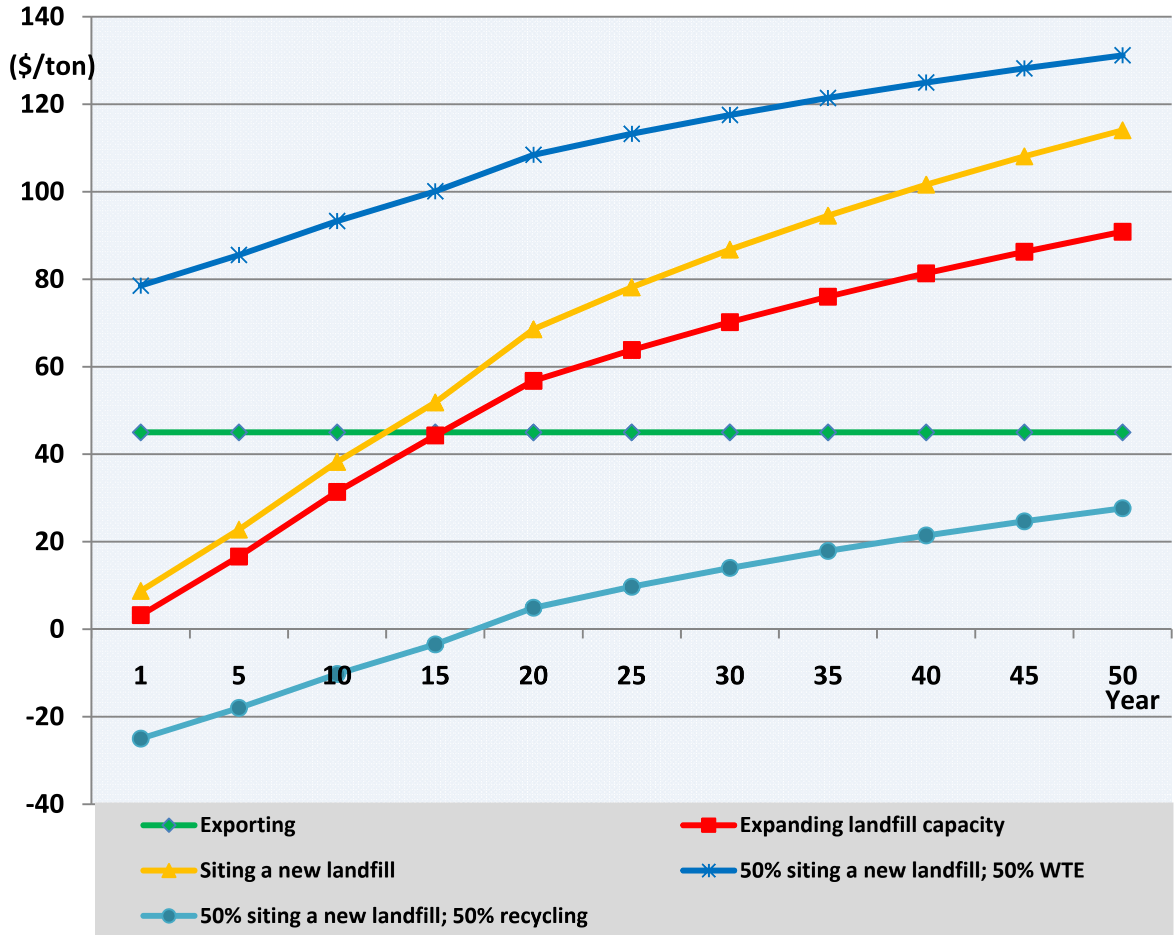

Figure 5.3: Cumulative Net Present Cost through MSW Management Life Cycle Including Indirect Impacts

Source: Author calculation based on data in Tables 5.1-5.2, C1-C2.

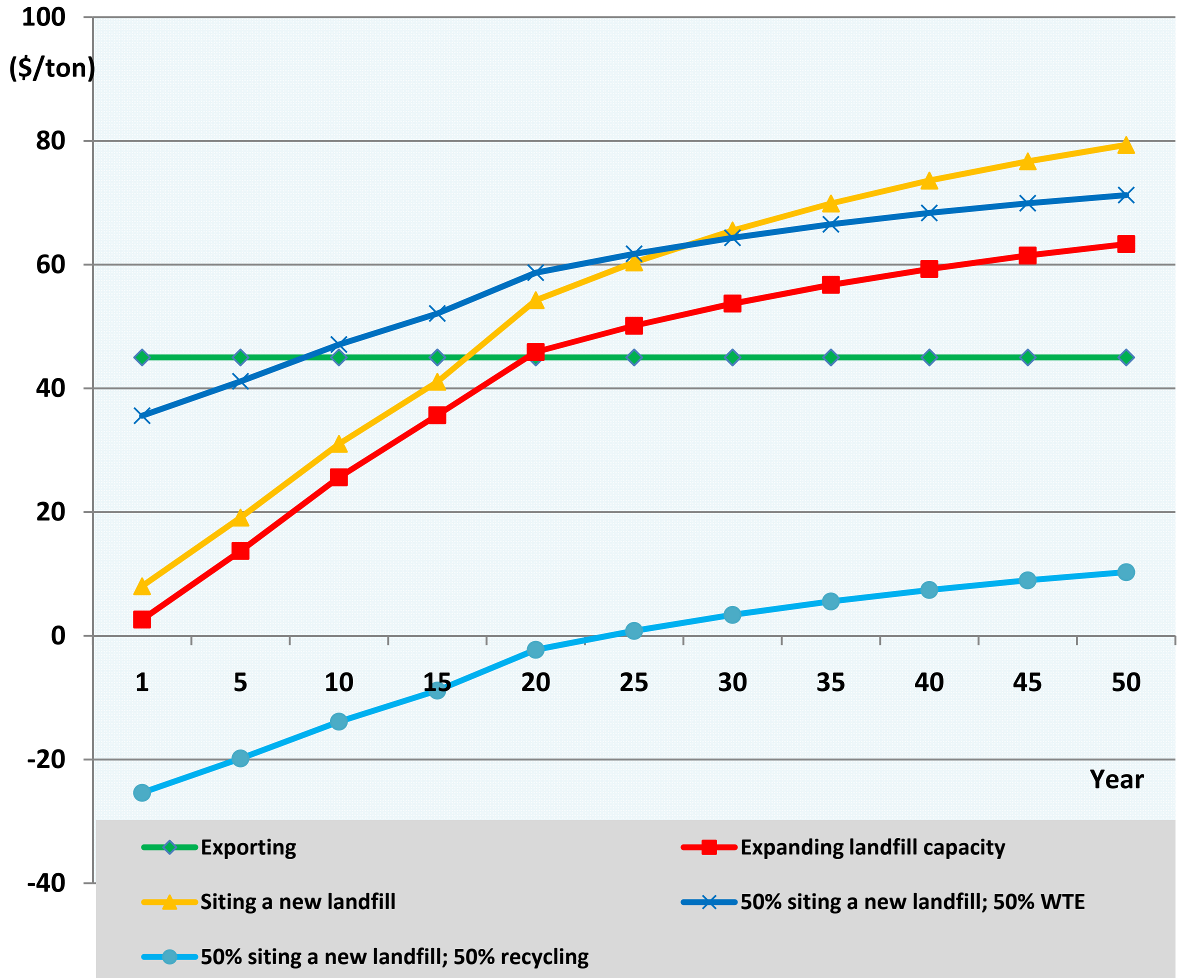

Figure 5.4: Cumulative Net Present Cost through MSW Management Life Cycle Including Indirect Impacts (Low External Costs)

Source: Author calculation based on data in Tables 5.1-5.2, C1-C2.

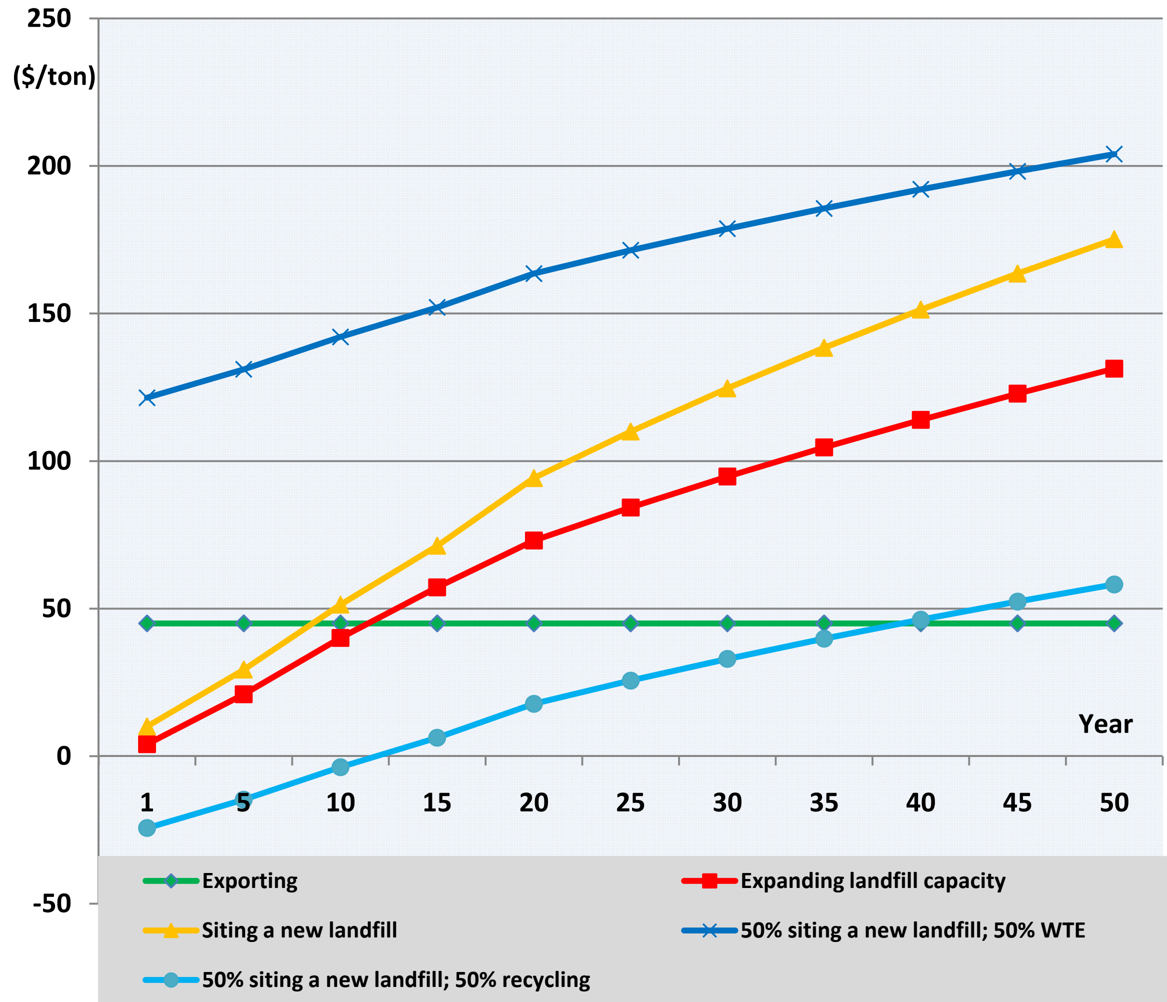

Figure 5.5: Cumulative Net Present Cost through MSW Management Life Cycle Including Indirect Impacts (High External Costs)

Source: Author calculation based on data in Tables 5.1-5.2, C1-C2.

POLICY IMPLICATIONS

This section demonstrated the importance of sustainable waste management to a region from a regional economic perspective. The findings from numerical analysis confirmed that timing is the key (short term vs. long term) when evaluating the waste management options. The comparison of the waste management options suggested that current waste management policies have mainly targeted short-term and direct impacts. Pro-landfiling activities appear to be the lowest cost solution and thus have bcome most favorable solution in the current practice. However, when considering the full costs of waste disposal activities, pro-landfilling activities incur higher cost than recycling, especially in the long run.

From a public policy perspective, instead of expanding the existing landfills either in size or number, efforts should target waste reduction through both economic incentives and technology advances. In particular, tipping fees and compensation programs should internalize the long-run external costs, because waste disposal activities may exert burdens on local economies as an exchange for short-term benefits. Continuing the unsustainable waste management practice at present incur much higher costs in the long run and accelerate the disparities among waste-import and export regions, in both environmental and socio-economic terms. The findings here are consistent with those from previous studies that the distribution of benefits and costs of landfills are uneven both in temporal and spatial terms (see Fort and Scarlett, 1993; Hite et al., 2001).

Although a full cost accounting method has been promoted by both federal and some state governments, short-term impacts are still the primary concern of most local decision-makers. This clearly suggests sustainable waste management options need to be financially viable to be appealing to local communities. Since the benefits of waste diversion cannot be revealed or magnified immediately in the waste transaction activity, waste reuse and recycling programs need to be more efficient to be competitive, e.g., via separation of dry and wet wastes or harvesting the economies of scale. Recycling can be, and should be, promoted from both the demand and supply sides. In particular, research and development (R&D) on using recycled materials should be promoted and the public sector should mandate the use of products recovered from recycled materials as one approach to advance the recycling industry. Municipalities should also endeavor to increase the efficiency of recycling. Currently, the unit cost of collecting recyclable materials is more expensive than garbage collection, because the recycling market is not stable and has not achieved the economies of scale as much as garbage disposal. Without increases in the recycling volume, its unit collection costs would remain higher than that of garbage collection. The good news is that advances in waste management technologies may enable some economic instruments that used to involve prohibitive administrative costs. For example, the refuse collection vehicle can now be equipped with a GPS and a chip card, which can record the location and the weight of waste collected (Stegmann et al, 2003). Such technologies would greatly facilitate a corrected fee system for MSW services, such as charging by volume or weight, as proposed by many economists (see for example, Jenkins, 1993; Fullerton and Kinnaman, 1996; Palmer and Walls, 1997; Podolsky and Spiegel, 1998).

A future refinement of the cost-benefit analysis using a multi-disciplinary approach would be necessary to identify who eventually bears the burden, who receives the benefits of landfills, and when. Only when these questions are answered, can the negative externalities of landfills be effectively internalized. It is also important to realize that waste management issues typically involve complex political and historical aspects that cannot be fully measured in economic terms. Thus, there would be no single standard method to evaluate the economic impacts of waste management and future studies should be always region- and community- specific.

CHAPTER 6

IMPACTS OF URBAN DEVELOPMENT PATTERN ON WASTE COLLECTION

This chapter expands the economic analysis and investigates what strategies local communities may develop for proactive and efficient waste management, with a special focus on the geographic characteristics. The spatial configuration of urban built environment, or urban form, directly determines the location for waste outputs, as well as material and energy inputs. Meanwhile, urban form has been a central subject of planning research in the recent decade. Despite researchers' disagreement on defining an ideal urban form, there is consensus that urban form affects human behavior and generates impacts on the environment, economy, and society, and thus plays an important role in sustainable development (see Anderson et al, 1996; Jabareen, 2006).

In particular, researchers have frequently focused on two development patterns - compact and sprawling. Some researchers criticize the potential problems of congestion as well as lack of individual preference and privacy associated with compact development. However, sprawling development, characterized as low-density, single-use, leapfrog, and separation of land uses, typically generates greater concern and has been criticized for creating negative impacts (as summarized in Table 6.1).

The debate on compact versus sprawling development has become more heated as researchers expand the primary focus from environmental and ecological impacts to socioeconomic considerations. Accordingly, the measurement method of urban form has been evolving too. In addition to the common indicator of density, researchers have further developed operational indicators of connectivity, accessibility, continuity, concentration, centrality, mixed use of land, and more (see Cutsinger et al, 2005; Ewing et al, 2002; Kahn, 2001; Malpezzi and Guo, 2001; Song 1996).

In contrast to the fruitful research on urban form, few existing studies, however, have considered the linkages between urban form and urban system residuals – specifically, the implications of urban form for waste management. Historically a public service, waste management used to be “out of sight and out of mind” to the general public. Thus, previous research in planning has been largely limited to the siting of waste disposal activities (see Lober, 1995; Hostovsky, 2000; Farhan and Murray, 2006). Intuitively, urban form determines the source of waste generation, the distance of waste collection and transportation, and the options of waste disposal. Combined, these activities determine the efficiency and effectiveness of local waste management. Moreover, their impacts spread across jurisdictions and generations.

Connecting waste management with urban form, this study aimed to provide new insights into planners’ role in waste management planning. It explored multidisciplinary literature that reveals the interactions between urban form and waste management. With a special interest in exploring the implications of sprawling development for waste management, this study developed a numerical analysis exploring the impact of residential density on waste collection cost. The chapter concludes with a discussion about the implications of urban form for waste management planning, and the role of planners, and future research areas.

Table6.1: Claimed Impacts of Urban Sprawl

Category	Impacts	Key References
Environmental	Emission resulted from auto dependency	Anderson et al. (1996)
	Increased fuel and energy use	Newman and Kentworthy (1988); U.S. EPA (2001)
	Faster consumption of land resources	Dwyer and Childs (2004); Landis (1995); Kahn (2000); Porter (2000)
	Loss or disruption of biodiversity	Harris (1984); Kautz (1993)
Economic	Higher infrastructure and public service costs	Burchell et al. (2000); Ewing (1997); Frank (1989)
	Inner-city decline	Frey and Fielding (1995); Wilson (1996)
Social	Racial segregation	Ewing (1997); Stoll (2005)
	Weakened social ties	Freeman (2001)
	Increasing obesity and blood pressure	Lopez and Hynes (2003); McCann and Ewing (2003); Saelens et al (2003)

LITERATURE REVIEW: URBAN FORM AND WASTE MANAGEMENT

While previous land use planning has largely limited to waste facility siting, multi-disciplinary literature suggests that urban form interacts with waste management in multiple ways. This section gathers empirical evidence from multiple disciplines and discusses the implications of community characteristics for waste management planning. In particular, this critical review has focused on three aspects: (1) waste stream characterization, (2) waste collection, and (3) management methods.

Urban Form and Waste Stream Characterization

Waste stream characterization data are derived from waste sorting surveys at the entrance of landfills or waste processing facilities, as a proxy of the composition of waste generated in a region. Without further information to differentiate waste disposal and waste generation stream, waste characterization data can reveal recycling potential and provide insights into efficient recycling design for a specific region. For example, if marketable materials, such as metal and paper, only account for a small portion of the waste disposed, the economic value that can be claimed from recycling would be low. This implies that more efforts by recycling programs may not achieve remarkable revenue, even after an increase of general recycling rate. In addition, if organic wastes, such as food residuals and yard trimmings, account for a large portion of the waste stream, then the community should consider investing more in a composting program.

The regional variations in waste composition among the few regions that have conducted waste characterization studies in the U.S. are evident. Figure 6.1 below provides an example by comparing waste components in the State of Georgia and the Atlanta metropolitan area, which has a denser development pattern than non-metropolitan areas in Georgia. Despite some similarities between metro and non-metro areas in Georgia, the data suggest that the waste stream from metro areas includes a higher percentage of paper, but lower percentages of metal, wood, and yard trimmings. A potential explanation for this is the differences in life styles in urban regions versus in suburban or rural areas. Waste stream in urban areas also differ from that in rural areas. Urban areas generate more paper and C&D wastes, while rural areas generate more glass and textiles. In other words, the potential of diverting waste from landfills can be different in metro areas versus non-metro areas, depending on the type of recyclable materials.

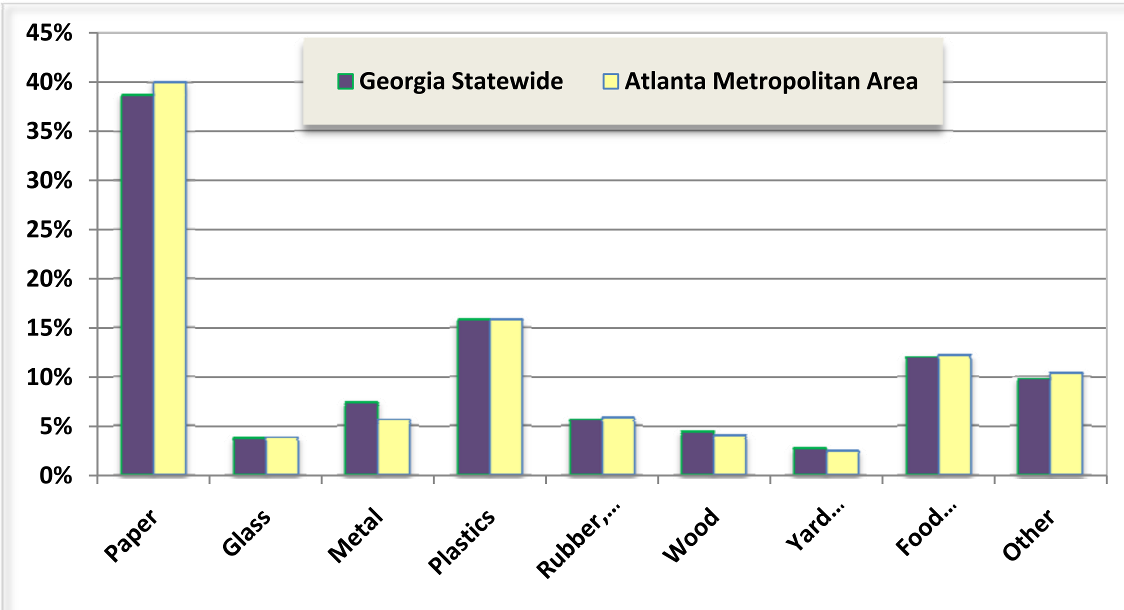

Figure 6.1: Waste Characterization in Georgia vs. Atlanta Metropolitan Area
Source: Georgia Department of Community Affairs. (2005). Georgia Statewide Waste Characterization Study. Report by R.W. Beck Inc.

Current waste characterization studies typically mix commercial, residential, and non-hazardous commercial waste as one waste stream, which coincides with the way it is disposed of. Thus, waste characterization data do not provide detailed information about waste generated from each sector, or by neighborhoods. A few studies, however, are pursued in other countries than the U.S. A study conducted by Fobil, Carboo and Clement (2002) examined the waste stream generated from three residential groups in Ghana: (1) High-Income Low-Density Population Waste Zone (HILDWZ), (2) Middle-Income Medium-Density Waste Zone (MIMDWZ), and (3) Low-Income High-Density population Waste Zone (LIHDWZ). Fobil and colleagues found that the waste stream generated by different groups "consists of entirely different proportions of the waste components". The authors suggest that different waste management schemes should be designed to suit the needs of each group, but it was not clear in their abstract what the benefit would be and how to do it in practice.[1]

Another example in Beijing, in Figure 6.2, shows the variations in the waste stream that is generated from one-story low-income residential areas, compared to that from high-rise apartments. The data suggest that low-income households living in one-story houses generate a higher percentage of organic waste and ash/dirt (from cooking and heating), but a lower percentage of metal, glass, paper and plastic waste, compared to high-income households living in high-rise apartments. Since the household income level is closely associated with the residential development pattern in this case, planners can develop different strategies for waste reduction and diversion in different neighborhoods. For example, increasing education and designing convenient recycling bins may help boost the recycling rate from high-rise apartments; for one-story low-income communities, however, promoting composting may be more effective than increasing recycling bins. In other words, strategies for waste diversion may not be effective for all the regions when ignoring its local characteristics.

[1] Note: This summary is only based on the article abstract. The full text is not available.

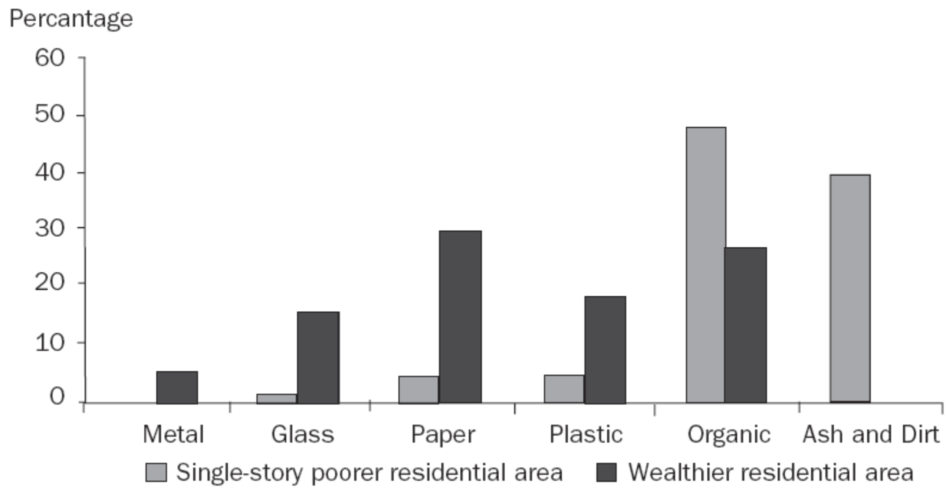

Figure 6.2: Variations in Waste Generation and Composition by Residence Affluence in Beijing
Source: Hoornweg, D. and Thomas, L. (1999). What a Waste: Solid waste management in Asia. Urban and Local Government Working Paper Series No. 1, The World Bank. Chart is from World Bank (2005).

Urban Form and Waste Collection

Many studies in both the U.S. and other countries have examined the influence of community characteristics on waste collection, and in particular, collection for recycling. These studies stressed the need for designing waste management programs that are community specific (Ai and Leigh, 2005). However, current practice does not adequately reflect such variations, and the literature to date has not provided sufficient insights into how to create these programs.

The work by Nino and Baetz (1996) first employed a quantitative approach of connecting urban form and waste collection activities through case studies in two hypothetical scenarios, that is, for a spread city and nodal city. The authors concluded that urban form plays a significant role in the travel distances of waste collection and transportation. Their work, however, assumed uniform household characteristics and equal distance between households. In addition, it ignored local demographic characteristics, such as income, education level, age, race, and household size, which previous literature concluded as important factors for household waste management behaviors (Ai and Leigh, 2005).

The only literature that revealed the impact of urban form on waste collection cost from empirical data is the report by the U.S. EPA (2001) that summarized its national survey of the cost and performance of residential waste management. The EPA's report had a primary focus on multifamily recycling, but also includes summary data on single family recycling. Among 118 responding communities that had multifamily recycling programs for at least one year, the EPA sampled 40 cities in four geographic regions (Appendix Table D.1). Over a decade afterwards, the EPA study (2001) remained the most comprehensive study of residential waste management in a relatively large number of cities for statistical study on waste management cost.

The cost of collection service examined in the EPA study refers to the cost incurred to the municipality. It can be the actual cost of municipal service, or the payment from the municipality to the private firm that provided the contract service. The recycling revenue remitted to the local municipality, if any, is deducted from the recycling cost. Thus, the recycling cost reported by the EPA study is rather a net cost. The garbage cost in the EPA study refers to the collection cost only; it excludes transfer or landfill disposal fees (p.25).

The summary data from the EPA's national surveys (presented in Appendix Table D.2 and illustrated in Figure 6.3 below) clearly suggested the differences in waste collection cost from multifamily and single family housing. The per-ton cost of collection for recycling from multifamily is almost doubled that for single family housing. In terms of refuse collection, in contrast, the cost for multifamily is much lower than that of single family. In addition, the cost of refuse collection for single family households tends to be higher when the recycling rate exceeds 20% because higher recycling rate leaves less refuse for collection in the city. As the recycle rate increases, the collection costs for recycling from both multifamily and single family housing decreases, suggesting that the economies of scale exist in the recycling practice. The total collection costs, which include collection costs for both recyclable materials and refuse, however, are not included in the study to allow us to make definitive conclusions.

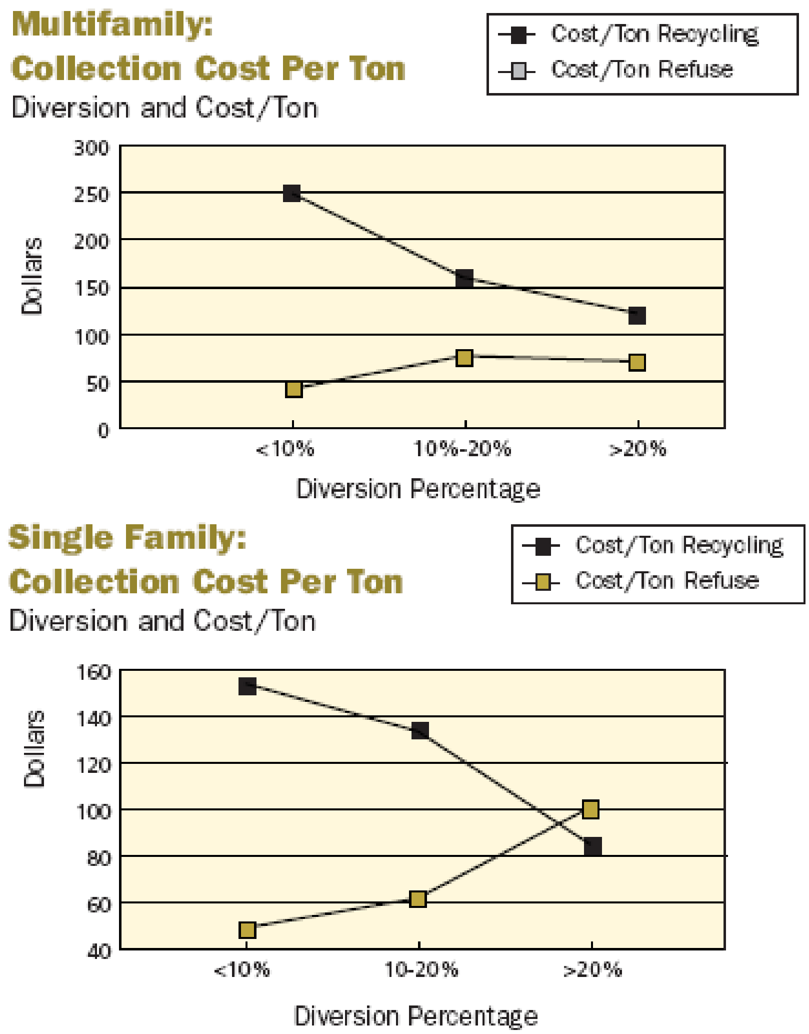

Figure 6.3: Waste Collection Cost for Multifamily and Single Family Housing

Source: U.S. EPA. (1999A.) Multifamily Recycling: A Golden Opportunity for Solid Waste Reduction. [http://www.epa.gov/epaoswer/non-hw/recycle/multi.pdf]

Urban form and Waste Management Methods

Based on the environmental impact assessment of existing waste management methods, the U.S. EPA has suggested a solid waste management hierarchy (see Figure2.4): landfilling and incineration are the least preferred method, and source reduction and reuse are the most preferred method followed by recycling and composting (U.S. EPA online information).

While the guideline of waste hierarchy proposed by the U.S. EPA is designed for general applicability, the study by Barrett and Lawlor (1997) discussed the difficulty of implementing it a low-density Ireland region, that has 38 inhabitants per sq km (compared to 257 in Germany, 104 in France, and 236 in the UK). Through a comparison of different waste management options, they concluded that "the cost of incineration and recycling by the collect system and re-use are considerably higher than the cost of landfill. Recycling by the bring system (and possibly composting) do appear to be viable alternatives for certain materials, though there are many uncertainties, mainly relating to price volatility of recyclables but also the possibly large external costs associated with bring recycling." The authors concluded that landfilling should be the optimal and primary solution for the MSW disposal in areas with low population densities.

The study by Barrett and Lawlor (1997) is perhaps the first that proposed to adapt the selection of waste management methods to the local land use pattern. The "one size does not fit all" thinking and the quantitative approach by Barrett and Lawlor (1997) is laudable, but their conclusions can be misleading. Although the authors have taken into account both internal costs and external costs (caused by negative externalities), they focused only on short term impacts. The potential negative impacts on the local community in the long run, such as housing depreciation after landfill construction and potential health risks to the community, have been largely ignored. In addition, without adequate data in their case study region, the authors referred to the data available in adjacent regions for their specific case study region. Heavy reliance on estimated numbers and data from other regions can easily raise doubts about the validity of their proposed region-specific waste policy design.

Findings from previous studies reveal that different urban forms indeed have impacts on the local waste management practice. Empirical data also suggest that differences in urban form and associated variations in waste stream may determine different strategies for efficient waste management. For instance, as illustrated in Figures6.4 and 6.5, single and multiple family housing units exhibit different characteristics in terms of waste recycling volume per housing unit and waste recycling rate. This suggests that one uniform system of waste collection from both single-family and multi-family households may not be the most efficient arrangement. Additional studies are needed.

In addition, each region may only be successful in recycling certain types of materials; second, different housing density and household structure in a city may result in different waste management costs from other cities with the same recycling rate; third, when measured in economic terms, recycling may not be always the optimal solution for waste management, given different population densities. Previous studies have clearly demonstrated the need for designing waste management policies to be community specific, but have provided few practical solutions.

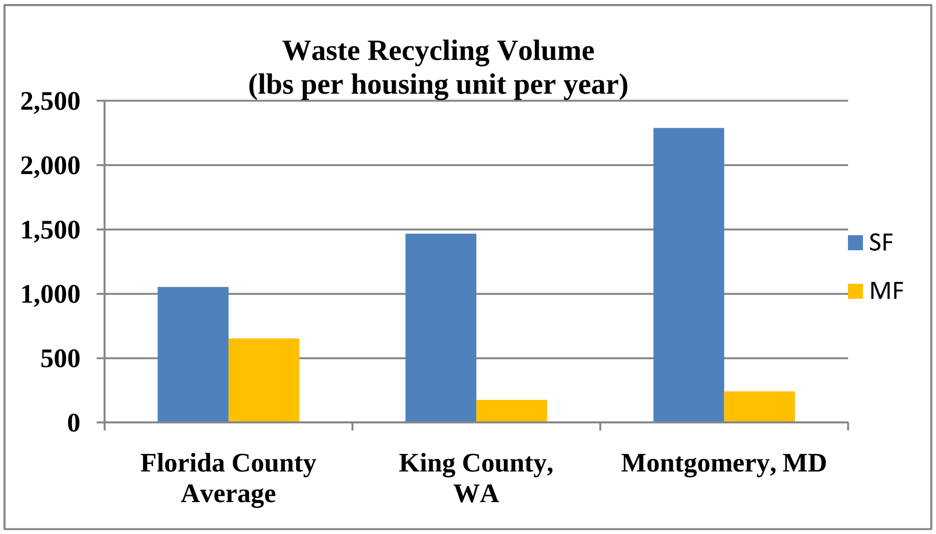

Figure 6.4: Waste Recycling Volume per Housing Unit for Single and Multiple Family Units

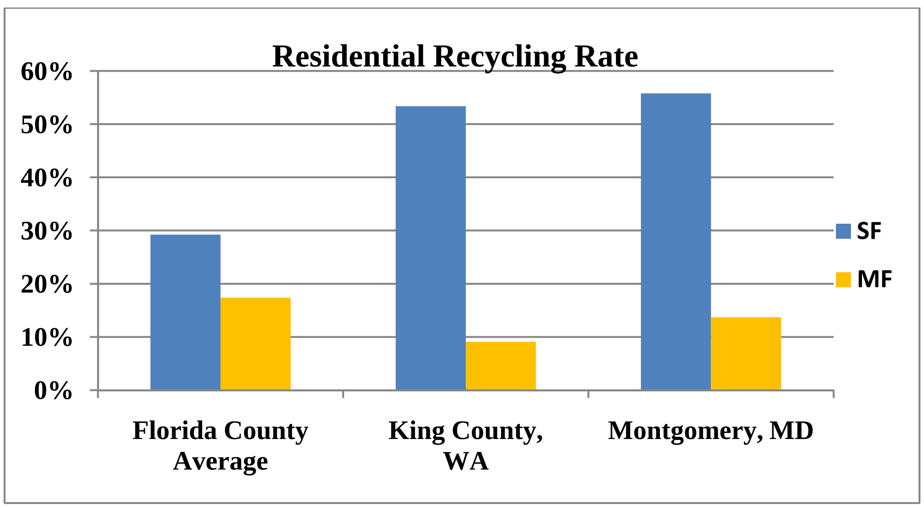

Figure 6.5: Waste Recycling Rate for Single and Multiple Family Units

Note: Data shown are of the latest year of data available: 2007 data for King County, WA; Year 2008 data for the others.

Data sources: [1] Solid Waste Division, King County, WA. (2007). 2007 Solid Waste Division Annual Report, King County, WA. [http://your.kingcounty.gov/solidwaste/about/documents.asp];
[2] Solid Waste Division, King County, WA. (2009). Draft 2009 Comprehensive Solid Waste Management Plan, King County, WA. [http://your.kingcounty.gov/solidwaste/about/planning/comp-plan.asp];
[3] Division of Solid Waste Service, Montgomery County, MD. (2009). Comprehensive Solid Waste Management Plan for the Years 2009 through 2019. http://www.montgomerycountymd.gov/swstmpl.asp?url=/content/dep/solidwaste/reference/index.asp;
[4] Florida Department of Environmental Protection. (2010). Solid Waste Management Annual Reports: 2000-2008. [http://www.dep.state.fl.us/waste/categories/recycling/SWreportdata/08_data.htm].

RESEARCH GOAL AND DATA AVAILABILITY

The goal of this study was to reveal the complex interactions between urban form and waste management. The questions of particular interest would include: given two neighborhoods with different development density (sprawling vs. compact), (1) how many miles a collection truck needs to travel to collect a ton of waste materials? And subsequently, (2) what are the emissions resulted from waste collection and transportation? and (3) what are potential strategies to minimize the transportation impacts?

Ideally, the unit of analysis should be the individual households, or waste management districts/waste collection routes, which are the sub-division of a county/city and designed to collect MSW efficiently. Waste statistics can be further linked to spatial information of road network and facility locations. However, only a few U.S. counties/cities collect waste generation data at a more refined geographic scale than a county. The data are collected through the pay-as-you-throw (PAYT) system, which charges households by the volume of waste generated and provides an economic incentive for waste reduction. By providing waste collection only if a household purchases specially designed trash bags, the municipality can estimate the total volume of waste that may have been generated on the basis of the number of trash bags sold. The PAYT system provides a potential opportunity for neighborhood-level analyses, but does not weigh the waste generated from each household. In other words, under the present system of waste management, household-level data can be obtained only through surveys, which determines that numerical analysis can only focus on certain areas.

The volume of recyclable materials from each household is not typically weighed or measured in the curbside recycling program. Recently, innovative programs, such as RecycleBank, record the weight of the recyclable collected from each registered households with RFID technology on the truck and provide financial reward to households by the frequency and volume that they recycle. RecycleBank was founded in 2005 and currently partners with about 30 U.S. municipalities in 20 states.[2] This would be the ideal data for the research questions. However, the company determined that the information is proprietary, and cannot be considered for public use or research.[3]

The only national survey covering a reasonable sample size was conducted by the U.S. EPA (2001), as introduced in the previous section, and thus, it will be the basis of this numerical analysis. Although the survey is outdated and only includes aggregated data, it was the only national level data set that is accessible to the public and that allows researchers to explore the trade-off between recycling and trash disposal for different residential densities.

RESEARCH DESIGN

This study relied on secondary data (U.S. EPA, 2001) and focused only on residential waste, which accounts for 55%-65% of total MSW generated in the U.S. Because garbage and recyclables are collected through different systems, they were examined separately. Since costs for collection and transportation account for up to 65% of the total cost of solid waste management (Phillips, 1998), this study focused on the

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[2]RecycleBank online information. Accessed on April 28, 2010 at [http://www.recyclebank.com/about]
[3] Latest email communications from Jeff Harse, Public Relations Manager, Recyclebank, 3/1/2011.

waste collection performance, which is measured by the "collection cost per ton of residential waste generated."[4]

In particular, this study focused on the comparison between high-density and low-density residential development. The hypotheses are: high-density development is associated with shorter distance for garbage collection and transportation, and thus has lower unit cost for waste collection. However, high-density development discourages households from recycling, given limited space for storage and composting, and thus results in higher unit cost for recyclable collection than those in low-density neighborhoods.

To measure residential density, this study chose the percentage of single family housing as a proxy indicator; a higher percentage of single family housing suggests a more sprawling pattern of residential development. To derive the collection cost per ton of total waste generated from neighborhoods of different residential density, the following steps were designed. First, the discrete data at three levels of recycling rate (i.e., <10%, 10-20%, and >20%) in the U.S. EPA report (2001) were extrapolated using a linear function. The assumption here is that the cost reduction due to economies of scale can be negligible at a low level of recycling and thus a linear function could be applicable for the data extrapolation. This assumption is supported by the high R square values

[4]As discussed explicitly in the EPA report, the indicator of "the cost per household without considering the quantity of materials recycled per household, can be deceptive. If the program provides weekly service but there is little participation, with crews driving the routes and finding setouts every tenth house instead of every other house, then the costs per household will be low but the cost per ton collected will be high. On the other hand, as a program becomes very effective in diverting a large portion of the discard waste stream, the cost per household may increase but the cost per ton collected may decrease, as it is less costly to collect larger quantities of material from a given number of stops than to collect small quantities of materials from a given number of stops, other things being equal."

(>0.75) obtained for three of the four functions. Because only a couple of communities in the U.S. have achieved a recycling rate higher than 50% and the effects of economies of scale on waste collection are unknown for any higher recycling rates, the cost data are extrapolated for recycling rates up to 50% only. Second, by assigning an arbitrary weight of 20%, 50%, and 80% of the residences as single family housing, this study integrated the collection costs from multifamily and single family housing, for garbage and recyclables, respectively. Lastly, this study combined the collection costs for garbage and recyclables (Step 2) and derived the total collection costs for cities with different mix of single and multifamily housing.

It is worthy to note that the cost item examined here differs from that in the numerical analysis in Chapter 5 in terms of both geographic and temporal scope. Thus, it is not straightforward to compare directly. Chapter 5 included collection costs in a full-cost accounting analysis. The simulation study was based in California, over a 50-year study period. This section zoomed into collection costs, and in particular, collection costs from households only. It is based on the national average data collected by the U.S. EPA and only provides a one-time estimate. Thus, a comparison in terms of the magnitude is more meaningful than comparing absolute numbers. Generally the collection cost is the primary cost component of waste management.

RESULTS AND DISCUSSIONS

Results derived from the steps above are presented in Figure 6.6. Clearly, the total cost of residential waste collection per ton varies for cities with different residential densities. Surprisingly, high-density residential development does not always present a cost advantage compared to low-density development. For example, when recycling rate is low (<25%), high-density residential development (e.g., 20% of single family housing) appear to incur higher collection cost per ton than low-density residential neighborhoods (e.g., 80% of single family housing). Given that the collection cost for recycling from multifamily housing is nearly double that of single family housing when recycling rate is lower than 10% (Figure 6.3), a higher percentage of multifamily housing seems to incur higher unit cost of collection if recycling is not promoted.

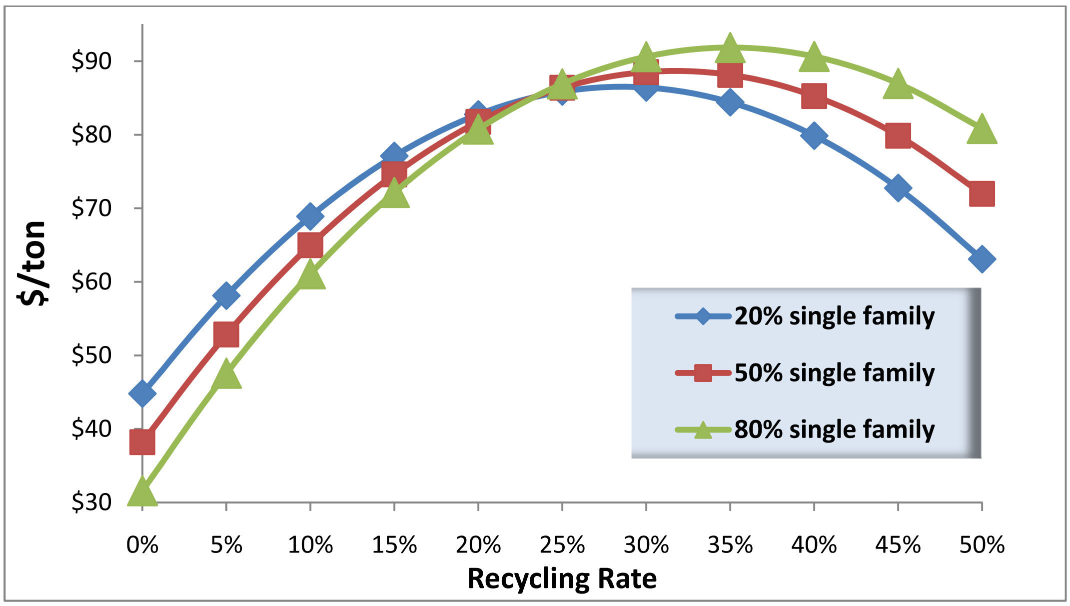

Figure 6.6: Estimated Collection Costs by Residential Mix and Recycling Target

Data are derived from the data reported in the U.S. EPA report (1999A). The percentage of single family housing in a region is arbitrarily selected by the author for scenario analyses.

Generally speaking, while cities of all three scenarios of residential density first experience increases in waste collection cost (even with increasing recycling rate), the total collection cost per ton decreases when the recycling rate gets to approximately 35% and higher. The results help explain the reluctance of many communities to boost recycling if it would only incur higher costs before the scale of recycling is achieved (e.g., 35% of recycling rate). While the absolute level of 35% recycling rate may not be accurate for all the cities, it is reasonable to conclude that all cities need to surpass a threshold of recycling rate before they can benefit from cost savings, regardless of their density.

This study suggested that public policy needs to provide a stimulus mechanism to help local communities to reach the level of scale so that they can maintain and develop on their own. Especially for communities with a higher percentage of multifamily housing, it is crucial to achieve a recycling rate of 20% or higher, when the collection cost for recycling becomes comparable to that for disposal under the current pricing system.

While current waste management programs have primarily focused on the disposal of the waste generated only, this study aimed to demonstrate that waste management activities interact with cities through the entire life cycle of waste materials and products. A good understanding of the local characteristics of urban form and its impacts on waste generation, collection, and processing activities is helpful and crucial for an economically efficient, environmentally effective, and socially equitable design of waste management policies.

This study compiled evidence from previous literature to demonstrate the need for incorporating local characteristics of urban form into waste management design. Further, it managed to reveal the cost implications of different residential density employing limited data from an EPA national survey. Notably, high-density development does not necessarily result in cost savings of waste management, especially when the recycling rate is low and most of the waste is sent to landfills or incinerators. Only when recycling rate reaches approximately 35% or higher, can communities experience decreases in unit collection cost, which could be an effective incentive to promote even higher recycling rate. While the goal here is not to produce precise number for investment decisions, the study demonstrated the need for strong support from the public sector to push local communities at the start-up of recycling, when, financially, it seems to be the most challenging stage of recycling, especially for densely populated areas with a high percentage of multifamily housing.

The goal of numerical analysis above is not to provide a precise figure for the public sector to make investment decisions. Rather, it aims to provide a generic model using empirical data to reveal cost structure for cities of different density.

While the preliminary analysis here using secondary data provides some important implications for residential waste management, it is limited to the single measure of "average residential density." The current waste management structure and resulting data availability did not allow a more comprehensive analysis of waste collection from the communities with mixed land uses, when commercial, office, and residence buildings co-exit. In addition, due to data availability, this study has only covered the cost comparison, in particular, collection costs. Only when the revenue from recyclable materials and landfill tipping fees in the local market are incorporated in the cost analysis, or the net cost is calculated, would numerical results reveal meaningful economic implications. While collection costs account for over half of the current waste management costs, waste planners also need to consider the local advantages as well as well as disadvantages in terms of waste processing, recovery, and disposal, for instances, in a full cost accounting approach. In particular, cost analysis from social and long-term perspectives is critically needed, such as the cost of facility post-closure care and the impacts on the local communities.

Given the limitations of aggregated survey data, this study could not incorporate demographic and other geographic characteristics into analysis. If neighborhood-level data become available in the future, local planning could associate waste collection with household demographic characteristics, such as household size, income level, and education level. Such information may be extremely valuable for waste management planning by planning from the source of waste generation, instead of managing the waste generated in a passive manner.

CHAPTER 7

SUMMARY AND POLICY IMPLICATIONS FOR SUSTAINABLE URBAN PLANNING

Through an interdisciplinary and integrated approach, this study explored the challenges of urban sustainability in the case of municipal solid waste management. This study examined interdisciplinary literature and developed empirical analyses to demonstrate the critical need of transforming the reactive nature of current waste management practice, and the challenges as well as opportunities for planners to contribute to proactive and efficient waste management program design. This concluding chapter summarizes the research questions and findings, discusses implications for sustainable planning and policy intervention, and concludes with a discussion of planners' role in promoting sustainable waste management in particular.

SUMMARY OF RESEARCH

To investigate sustainable solutions for growing urban regions, this study conducted both theoretical and empirical analyses. In the theoretical discussions, this study reviewed four themes of theory: urban planning, urban systems research, environmental economics, and regional economic development. The theoretical discussions looked into waste management practice from the micro-level of consumers, waste generators, waste industry operators, to the micro-level of urban systems and regional economic systems. Theoretical discussions revealed that the externalities of waste management practice and exclusive focus on immediate impacts have caused inefficient operation of waste management operation. Waste management planning necessitates a long-term and system approach, and community-specific policy design.

Beyond theoretical discussions, this study had a special focus on seeking empirical data for three inter-related analyses: (1) Whether waste generation can be decoupled from urban population growth? If yes, what factors may have caused waste reduction? (2) Why the environmentally least preferred waste management method, landfill disposal, has been the primary method of MSW management? And what are the implications of pro-landfilling practice for regional economic development? And, (3) What strategies local communities may develop for proactive and efficient waste management?

For the first question, this study looked into the details of waste statistics across 39 fast-growing counties in the U.S. between2000 and 2005. The results from correlation analyses confirmed that population growth was not always associated with increases in waste generation. Next, a panel data analysis was conducted to examine the explanatory variables and potential areas for waste planners to focus on for waste reduction. This study adopted two-way fixed effects models to capture unobserved time effects that change over time (such as economic conditions) and county effects that are unique to each county (such as climate and consumption pattern). This study found that: (1) waste reduction programs, such as pay-as-you-throw (PAYT, variable unit pricing for garbage collection) facilitated waste reduction, (2) counties with older buildings generated more waste per capita; (3) counties with PAYT and higher household income recycled more waste. The results suggested that heterogeneous characteristics present different challenges of waste reduction goals. However, economic incentives were effective in waste reduction; cost considerations dominated.

The second empirical analysis continued discussions on the economic perspectives of waste management. It employed a full cost accounting approach and compared five different waste management options (including building new landfills, expanding landfills, exporting, promoting recycling, and waste-to-energy) in a simulation study. This study had a special focus on landfill disposal, because it is the environmentally least preferred method of waste management but has been used as the primary method in practice. The empirical study demonstrated that pro-landfilling activities presented cost advantage in the short run, but experienced cost jumps after facility closure for long-term maintenance and pollution control. This study suggested that pro-landfilling activities may create revenues for distressed areas but cannot sustain growth in the long run. Pursuing short-term benefits of low-cost landfilling option only creates higher cost burden for future. Because current pricing of landfill disposal does not provide correct incentives for waste reduction, short-term cost considerations have discouraged recycling,

The third research question investigated the strategies for local communities to achieve proactive and efficient waste management, given their unique geographic characteristics. This study reviewed interdisciplinary literature that reveals the variance of waste stream characterization, collection cost, and management methods in different geographic areas and stressed the need of community-specific waste policy design. Specifically, this study conducted a simulation of waste collection costs for communities varying in terms of residential mix (single-family and multi-family), in response to the central issue of compact vs. sprawling development. This study employed the EPA (2001) national survey data, developed extrapolation method for the aggregated data set, and integrated the collection costs for garbage and recyclables for cities with different mix of single-family and multifamily housing. This research revealed a surprising finding that high-density residential development (with higher percentage of multi-family housing) does not always present a cost advantage compared to low-density development. For example, when recycling rate is low (<25%), high-density residential development (for example, 80% of multi-family housing) appear to incur higher collection cost per ton than low-density residential neighborhoods (for example, 80% of single family housing). In general, all cities need to reach the threshold before they can benefit from cost savings from recycling programs, regardless of their housing density. Therefore, public policy needs to provide a stimulus mechanism to help local communities to reach the level of scale so that they can maintain and develop on their own. Policy support at the initial stage of recycling programs is crucially needed to make them financially viable, especially for communities with a higher percentage of multifamily housing.

POLICY IMPLICATIONS

When reflecting on the current waste management practice and the need for sustainable waste planning (illustrated in the introduction chapter, Figure 1.1), there are great gaps between what has been done and what should be done. Summarizing the discussions elaborated in the previous chapters, this section focuses on four issues that should be of central concern to policy makers.

Life Cycle and System Thinking

As revealed from the evolvement of waste management regulations and legislation, waste management practice has generally focused on a reactive approach; progressive actions are only made when serious problems occurred. At the local level, waste management practice has generally focused on the immediate impacts and end-of-the-pipe solutions. The focus has been the issues at the operational level in terms of how to "get rid of" the waste generated, instead of reducing the waste volume at the first place.

This research demonstrated the need of long-term life cycle planning of waste management. As illustrated in Figure 2.3, the environmental impacts of waste generation are not limited to the disposal stage; they start from raw material extraction, and go through production, manufacturing, transportation and consumption stages. While economic incentives for waste reduction have been effective at the stage of waste discard, waste-reduction incentives need to be introduced through all the stages of production and consumption.

Solid waste minimization efforts also need to consider the impacts on other environmental media, such as air and water. A reduction of solid waste volume disposed in landfills may be associated with an increase of burden on sewer (such as kitchen food disposal) and air (such as burning MSW in incinerators). Sustainable urban systems necessitate a system view of material and energy flows. Fundamentally, a transformation of mindset is needed from considering waste as useless materials to developing closed-loop strategies to find recycle and reuse opportunities within the urban system.

Waste Statistics Availability and Quality

The fundamental information about material flows for proactive waste management, however, is not commonly available as other services, such as water or electricity. The challenges associated with data inadequacy, inconsistencies, and uncertainties are presented in every numerical analysis of waste management. As discussed in previous research (Leigh, et al., 2007b), waste management research is greatly hindered by the availability and quality of waste statistics, rather than the research methodology per se.

While waste management agencies have endeavored to track and record waste statistics, there are significant inconsistencies across jurisdictions. Increased, integrated, and consistent efforts are needed to promote the development of better quality of waste management datasets, through field surveys, rigorous research, and application of advanced technology (such as the RFID for waste generation tracking). In addition, public sector should play an increasing role in facilitating waste management data-sharing across sectors and regions.

Private vs. Public Roles in Waste Management Practice

Historically a public service, waste management activities have increasingly involved private sectors in the recent years. The participation and competition across private sectors can achieve cost savings, reduce the burden of public sector alone, and thus help improve the effectiveness and efficiency in waste management.

However, the negative externalities associated with waste management activities determine that public sector still needs to play an important role. In particular, public sector needs to balance the trade-off between efficiency in waste management operation and equity of cost-sharing across regions and generations. In addition to integrating externality cost into waste management pricing, public sector needs to play a stronger role in public education, to universal consumers, manufacturers, and waste management operators. Public education is particularly important since waste management practice has been increasingly privatized. Consumers need to be motivated to play a role in promoting recycling and thus discourages private sectors' waste disposal activities.

PLANNER'S ROLE IN SUSTAINABLE WASTE PLANNING

While city planners' involvement in waste management has been largely limited to waste infrastructure siting, planners have great potentials to contribute to sustainable waste planning in terms of both practice and research.

First of all, planners have a special focus on spatial implications of policy making and are familiar with local and regional demographic characteristics as well as the built environment, which provides the basis for material and waste flow analysis and community-specific waste management policy design (Leigh et al., 2007b). In particular, there is great potential for planners to identify material flows through urban systems, given that land use and zoning determines the destination of material inputs and source of waste generation.

Second, planners have access and can make the influence on infrastructure planning, which could include not only landfill and WTE facilities, but also recycling centers, drop-off sites, and even remanufacturing facilities within urban centers. Strategic plans, such as locating waste management facilities in greyfields, can mitigate environmental consequences of material flows, advance closed-loop production systems within urban areas, and promote increased economic opportunities for urban residents (Leigh, et al., 2007a)

Third, planners are adept at using local data for dynamic estimates of infrastructure and community planning, and waste management programs may naturally fit in the long-term plan. Thus, planners naturally process the knowledge and skills for long-term waste management planning. One approach of integrating waste management into long term planning could be designing urban sustainability indicators from a system perspective and promoting regular data collection in a consistent format.

Fourth, planners hold a holistic view of a region and are most capable of managing the highly interdisciplinary issues of waste management. A good understanding of the complexity in waste management helps minimize the conflicts between stakeholders and planning objectives in waste planning, from the beginning of material extraction and production, instead of the narrow focus on its final destination.

Fifth, planners have the access to influence the business development strategies and promote environmentally conscious production activities. In particular, planners can promote the network of businesses that cooperate with each other through exchange or sharing of resources (information, materials, water, energy, infrastructure and natural habitat) to achieve both economic and environment gains, as the notion of "industrial symbiosis" suggests.

Sixth, a more vigorous approach than the voluntary one discussed above for planners is to advocate for federal legislations and coordinated regional efforts for management. Even and consistent enforcement methods should be developed to discourage waste export to other regions, facilitate advancement and adoption of green technology, and promote self-reliance of waste management for each urban region.

Last but not least, planners can and should contribute to public education and help transform the public perception of waste. In particular, public education should address the life cycle impacts of consumption and the long-term risks of waste disposal facilities, which are immediately tangible and measurable. Economic incentives and technology advances still need the support of public education to be feasible and efficient for waste reduction, which is the primary condition for urban sustainability.

APPENDIX A

Table A.1: Comparison of U.S. National Waste Statistics from EPA and Biocycle Magazine

Comparison Category	U.S. EPA	Biocycle
Data collection approach	Product life cycle (e.g., production, consumption, import, export)	National survey of state agencies
Data processing approach	Adjust national material flow data by population data and historical records of waste flow information at state level	Aggregate state level data for national total
Measurement of disposal volume	Exclude C&D debris, biosolids, industrial process wastes, and some other wastes even if they are disposed in MSW landfills	All wastes entering MSW landfills through weighing scale
Measurement of recycling volume	Composting is considered as a separate category.	[1] Recycling and composting are combined when calculating the recycling rate. [2] Recycling rate collected through the survey approach may involve over-estimates.
Frequency of publication	Annual publication with annually updated data.	Annual publication with latest data available.
Limitations	Data required for this estimation approach are not commonly available below the national level.	[1] Does not resolve the inconsistency in data reporting and recording methods across regions. [2] Not every state responds to the surveys.

APPENDIX B

COUNTY WASTE STATISTICS REFERENCES

TableB.1:Data Sources of County Waste Statistics
(Sorted by State Name, then County Name)

County	State	Data Source	Reporting Agency	URL
Contra Costa County	California	Countywide, Regionwide, and Statewide Jurisdiction Diversion/Disposal Progress Reports (2000 & 2005)	California Department of Resources Recycling and Recovery (CalRecycle)	http://www.calrecycle.ca.gov/LGCentral/Tools/MARS/jurdrsta.asp
Riverside County	California			
San Bernardino County	California			
San Joaquin County	California			
Ventura County	California			
Broward County	Florida	Solid Waste Annual Reports (2000 & 2005) Tables 5A: Final Disposition of Municipal Solid Waste in Florida	Florida Dept of Environmental Protection, Division of Waste Management	http://www.dep.state.fl.us/waste/categories/recycling/SWreportdata/archive.htm
Duval County	Florida			
Hillsborough County	Florida			
Lee County	Florida			
Manatee County	Florida			
Miami-Dade County	Florida			
Orange County	Florida			
Palm Beach County	Florida			
Pasco County	Florida			
Polk County	Florida			
Sarasota County	Florida			
Seminole County	Florida			
Volusia County	Florida			

TableB.1:Data Sources of County Waste Statistics (continued)

County	State	Data Source	Reporting Agency	URL
Lake County	Illinois	Solid Waste Management Reports (2000 & 2005) Appendix M	Illinois Environmental Protection Agency, Bureau of Land, Division of Land Pollution Control	http://www.epa.state.il.us/land/landfill-capacity/
McHenry County	Illinois			
Will County	Illinois			
Anoka County	Minnesota	Governor's Select Committee on Recycling and the Environment (SCORE) Program Reports (2000 & 2005)	Minnesota Pollution Control Agency	http://www.pca.state.mn.us/index.php/topics/environmental-data/score/recycling-and-solid-waste-data.html
Dakota County	Minnesota			
Washoe County	Nevada	[1] State of Nevada Solid Waste Management Plan (2007) Appendix 3: County Solid Waste Profile (1999, 2001, and 2005) and Section 2.3 Waste Generation and Recycling [2] Nevada 2003 Recycling Status and Market Development Report	Nevada Division of Environmental Protection	[1]http://ndep.nv.gov/bwm/swmp/swmpprint.htm [2]http://nevadarecycles.gov/main/status02.htm
Forsyth County	North Carolina	[1] N.C. Solid Waste Management Annual Reports Appendix B (1999, 2000, 2005 & 2006) [2] N.C. Dept of Environment and Natural Resources Press Releases (5/30/2006) [3] N.C. Dept of Environment and Natural Resources Press Releases (5/17/2007)	North Carolina Dept of Environment and Natural Resources, Division of Waste Management	[1]http://portal.ncdenr.org/web/wm/sw/reports [2]http://www.p2pays.org/press_releases/37848.pdf [3]http://www.p2pays.org/press_releases/051707.pdf
Guilford County	North Carolina			
Mecklenburg County	North Carolina			
Wake County	North Carolina			

TableB.1:Data Sources of County Waste Statistics (continued)

County	State	Data Source	Reporting Agency	URL
Berks County	Pennsylvania	[1] County Waste Disposal Reports (2000 & 2005) [2] Pennsylvnania's Recycling Program: 2000-2001 Act 101 Annual Report to the General Assembly of Pennsylvania [3] 2006 County Recycling Report	Pennsylvania Dept of Environmental Protection Bureau of Waste Management	[1]http://www.portal.state.pa.us/portal/server.pt?open=514&objID=589667&mode=2 [2]http://www.elibrary.dep.state.pa.us/dsweb/Get/Version-45909/2520-BK-DEP2586%202000-2001.pdf [3]http://www.dep.state.pa.us/dep/deputate/airwaste/wm/RECYCLE/Recycle.htm
Chester County	Pennsylvania			
Lehigh County	Pennsylvania			
Northampton County	Pennsylvania			
York County	Pennsylvania			
Charleston County	South Carolina	Solid waste management annual reports (2000-2006)	South Carolina Department of Health and Environmental Control	http://www.scdhec.gov/environment/lwm/recycle/annual_report.htm; www.scdhec.gov/recycle/html/pubs.html.
Greenville County	South Carolina			
Richland County	South Carolina			
Clark County	Washington	[1] Clark County Comprehensive Solid Waste Management Plan 2008 (Tables 15.2 and 15.3) [2] Clark County Comprehensive Solid Waste And Moderate Risk Waste Management Plan 2000 - Chapter 6	Clark County Environmental Services	[1]&[2]http://www.co.clark.wa.us/recycle/documents.html
Pierce County	Washington	Tacoma-Pierce County Solid Waste Management Plan (2008 supplement Appendix-20)	Pierce County Department of Public Works and Utilities	http://www.co.pierce.wa.us/pc/services/home/environ/pdf/solidwaste/pdf/2008plan.htm

TableB.1:Data Sources of County Waste Statistics (continued)

County	State	Data Source	Reporting Agency	URL
Spokane County	Washington	[1] Spokane County Profile: Disposal Site Summary (in 2001) [2] Spokane County Solid Waste Annual Report (2006) [3]Recycling Rate Report (A Summary of 1999-2008)	Spokane Regional Solid Waste System	[1]http://www.ecy.wa.gov/programs/swfa/profiles/spokane.pdf [2]http://www.solidwaste.org/subdf2c.php?id=5151 [3]www.solidwaste.org/uploads/Recycrate2008.XLS

APPENDIX C

DATA REFERENCES FOR ECONOMIC ANALYSIS OF WASTE MANAGEMENT

Table C.1: Recovery Value of Recyclable Materials in MSW

	Weight Generated (tons)	% Recovered	Market Value Low End ($/ton)	Market Value High End ($/ton)
Paper and paperboard	83	51	80	280
Glass	14	8	8	30
Steel	16	10	90	347
Aluminum	3	2	1,240	4,060
Other non-ferrous metals	2	1	6	79
Plastics	31	19	21	36
Wood	14	9	12	24
Total MSW Recycled	162	100		
Total MSW Generated	254			
Weighted Recovery Value			**81**	**273**

Source: Waste weight data are provided by U.S. EPA. (2008B). Municipal Solid Waste in the United States: 2007 Facts and Figures. Market values of recycled materials are collected from multiple sources, mainly including (1) American Metal Market at www.amm.com; and (2) Demolition Scrap Metal and Salvage News at http://demolitionscrapmetalnews.com/; and (3) Falk and McKeever (2004) Recovering Wood for Reuse and Recycling a United States Perspective, Proceedings of Management of Recovered Wood Recycling, Bioenergy and Other Options, edited by Christos Gallis. Thessaloniki: University Studio Press, 2004: pp. 29-40.

Table C. 2: Data Sources and Notes for Calculation of Property Tax Loss Due to Landfill

Parameters	**Data Sources**
Radius of area with negative impact on property value caused by proximity to landfill (miles)	In most studies, the maximum effect range varies between 2.5 and 4 miles from a landfill with an average of 3.25 miles (Eshet, 2005). Some other studies indicate that there can be no negative impact in house value caused by landfill (Ready, 2005). This dissertation assumes a low value of 0; an average value of 2 miles; and a high value of 4 miles in sensitivity analysis.
Average house density per square miles of land area adjacent to landfill	This dissertation assumes a value of 78.3/square miles. Source: (U.S. Census, 2000).
Average percentage of property value depreciation caused by proximity to landfill	In most studies, the amount of house price depreciation varies based on the proximity to a landfill, which is in the range of 1.2% per mile to 10.0% per mile (Ready, 2005) and (Eshet, 2005). This dissertation assumes an average depreciation of 12.9% in the entire impacted area (Ready, 2005).
Average property tax rate in California	This dissertation assumes a value of 0.68%. Source: (Moody's Economy.com, 2007).
Annual rate of increase of median house prices in California	This dissertation assumes of value of 2.98%, which is obtained based on a median price of $23,210 in year 1968 and a median price of $346,750 in year 2008. Source: (California Association of Realtors, 2009)

APPENDIX D

ADDITIONAL INFORMATION ABOUT THE U.S. EPA RECYCLING SURVEY

Table D.1: Communities Selected for the U.S. EPA Multi-Family Recycling Analysis

Alameda, CA	East Orange, NJ	Lima, OH	Roswell, GA
Altoona, PA	Fountain Valley, CA	Maple Grove, MN	Saint Paul, MN
Bridgewater, NJ	Frankfurt, KY	Miami, FL	San Jose, CA
Broward County, FL	Greenfield, WI	Newport News, VA	Seattle, WA
Cherry Hill, NJ	Hillsboro, OR	New York City, NY	Syracuse, NY
Dayton, OH	Jacksonville, FL	North Tonawanda, NY	Tamarac, FL
Daytona Beach, FL	Lakewood, OH	Old Bridge, NJ	Tampa, FL
Diamond Bar, CA	Lancaster, OH	Olympia, WA	Vista, CA
Durham, NC	Laredo, TX	Placentia, CA	University City, MO
East Brunswick, NJ	Largo, FL	Portland, OR	Wallingford, CT

Source: U.S. EPA. (2001). Multifamily Recycling: A National Study. EPA530-R-01-018. November 2001.

Table D.2: Performance Indicators of Waste Collection: Single family vs. Multifamily

	Multifamily Curbside Diversion			
Value	<10%	10-20%	>20%	Statistical Significance**
Number of Observations	**13**	**16**	**11**	**40**
Collection Cost/Ton				
Multifamily Recycling*	$251.00	$159.00	$113.00	Yes-95%
Multifamily Refuse	$43.13	$72.60	$66.39	Yes-99%
Single Family Recycling	$151.80	$131.70	$81.64	Yes-99%
Single Family Refuse	$47.48	$60.28	$101.32	Yes-99%
Single Family Yard Trimmings	$75.03	$51.48	$127.16	No
Collection Cost/Household/Year				
Multifamily Recycling	$16.63	$20.56	$21.81	No
Multifamily Refuse	$45.17	$72.34	$36.01	No
TOTAL PER MF HOUSEHOLD	$61.80	$92.90	$57.82	
Single Family Recycling	$21.65	$30.96	$24.73	No
Single Family Refuse	$58.69	$64.71	$84.01	Yes-90%
Single Family Yard Trimmings	$16.05	$20.67	$15.89	No
TOTAL PER SF HOUSEHOLD	$96.39	$116.34	$124.63	
Households/Crew Shift				
Multifamily Recycling	2,333	2,246	1,676	No
Multifamily Refuse	1,205	1,537	2,144	No
Single Family Recycling	1,561	1,549	1,629	No
Single Family Refuse	618	1,142	3,962	Yes-90%
Tons/Household/Year				
Multifamily Recycling	0.061	0.145	0.211	Yes-99%
Multifamily Refuse	1.023	0.934	0.595	Yes-95%
TOTAL MF Municipal Solid Waste	1.084	1.079	0.806	Yes-95%
Single Family Recycling	0.139	0.260	0.297	Yes-99%
Single Family Refuse	1.312	1.123	0.951	Yes-95%
Single Family Yard Trimmings	0.317	0.258	0.209	No
TOTAL SF Municipal Solid Waste	1.768	1.641	1.457	Yes-95%
Curbside Diversion Rates				
Multifamily Recycling	6.04%	13.93%	27.76%	Yes-99%
Single Family Recycling	9.25%	17.70%	20.39%	Yes-99%
Single Family Yard Trimmings	16.94%	15.90%	12.48%	No
Complaints/Household/Year	**0.017**	**0.040**	**0.017**	**No**

* Excludes two cities with very high per ton costs, in the less than 10% diversion group.

** Indicates whether or not the difference in values is statistically significant, and the confidence level with which the null hypothesis of no difference can be rejected.

Source: U.S. EPA.2001. Multifamily Recycling: A National Study. EPA530-R-01-018. November 2001. P.3.

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